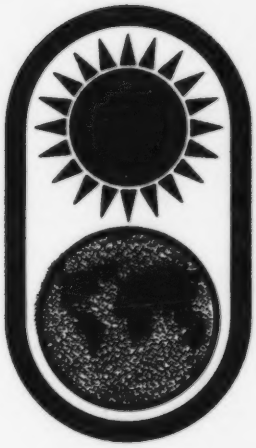

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CONTRACT REPORT NO. OSQ78-00238

FINAL REPORT, PHASE I

JULY 1979

DEVELOPMENT, INSTALLATION AND OPERATION OF A SUBSIDENCE MONITORING AND TELEMETRY SYSTEM

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1. INTRODUCTION

This report presents the results of Phase I of the project "Development, Installation and Operation of a Subsidence Monitoring and Telemetry System" in a coal mining area near Sparwood, B.C. This project was contracted to Ecological and Resources Consultants Limited in Fredericton (called Consultants in this report) by CANMET, Mining Research Laboratories, Western Office in Calgary on March 30, 1979.

Phase I of the contract called for:

1.i) Conduct a comprehensive study of subsidence measurement and telemetry systems and photogrammetry technology that have or may be applied to the mining conditions in relevant mountain terrain (Sparwood Mountain, B.C.).

1.ii) Recommend systems for the field conditions below:

a) the slope angles to 45^{o},
b) temperature ranges -25^{o} to $40^{o}C$,
c) winter snow cover heavy, up to 15 feet,
d) surface cover consists of bush and trees on a thin sandy soil,
e) no access road to the proposed measurement site within 5 kilometres,
f) system must be capable of monitoring surface stations within a radius of 5000 metres at elevation differences up to 1000 metres.

2. Design or adapt a prototype measurement/monitoring/telemetry system applicable to field conditions above.

3. Prepare a report of Phase I which will include a reassessment of Phase II contract requirements and costs.

The Consultants have completed all of the above tasks. Details of the work were reported in three monthly progress reports (April, May, and June). Some of these are repeated in this report while others are only referenced to the corresponding monthly reports.

The bibliography and literature on subsidence theories and monitoring,

which were collected during the study are not attached to this report. Copies can be made available to the Science Authority in Calgary if requested.

2. FORMULATION OF THE APPROACH

2.1 Basic Concept and Selection of the Telemetric Monitoring System

The basic concept had been outlined in the Consultants' proposal for the contract which was submitted to the Department of Supply and Services in Ottawa on July 18, 1978. As mentioned there, the following three methods may be considered in monitoring terrain subsidence caused by coal mining in the Sparwood area:

1. Repeated positioning of selected marked points employing geodetic or photogrammetric surveys.
2. Repeated profiling of selected terrain lines using photogrammetric measurements.
3. Determination of relative displacements of points by employing rock mechanics instrumentation such as tiltmeters and/or strain meters.

Given the climatic conditions of Sparwood, the first two methods cannot be applied on a year-round basis. They also do not allow for a continuous telemetric monitoring of the ground movements. These methods, however, have not been completely discarded and the Consultants recommend to use those methods (see Chapters 4. and 6.) as the back-up monitoring system during the summer months as well as an independent check of the information collected and accumulated by the proposed telemetric system.

The rock mechanics instrumentation, if properly designed and

installed can survive the severe winter conditions and allows for a continuous telemetric monitoring of the ground movements. A weakness of the system based on the rock mechanics instrumentation is that the instruments do not monitor directly the absolute ground movements and subsidence profile. This information must be derived and "extrapolated" from the local in-site detections of either strains when using strainmeters, or tilts,when using the tiltmeters. Therefore, the first method, though very useful in the determination of local deformation for rock behaviour studies, is inferior to the geodetic surveying methods in the determination of absolute movements of terrain points over large areas. Nevertheless, the method based on the rock mechanics instrumentation appears to be the only economical method for telemetric monitoring of the movements, particularly during the winter months. One could consider other solutions such as targetted points elevated on special constructions above the snow level and automatic repeated positioning of the targets using long range laser interferometry or electromagnetic distance and angle measurements with a sweeping line of sight and automatic recording, but these methods are beyond any economical and scientific justification.

When choosing the type of the rock mechanics instrumentation, the tiltmeters offer an obvious advantage over the strainmeters in the subsidence determination because the tilts may be much easier translated into the changes of elevations between two tiltmeter stations than the strains. This is apparent from the basic theory of the ground subsidence discussed in the next chapter.

Therefore, the concept of the telemetric system elaborated by the Consultants is based on the use of tiltmeters. Change of the

mechanical tilts are transformed into electric signals, which in turn are changed into radio frequency signals and transmitted by a RF system to a receiver located in a convenient place.

The use of the tiltmeters in the subsidence determination is explained in Figure 2.1.

If several tiltmeters are located along the profile line of the subsidence basin (Fig. 2.1) then the subsidence on any part of the profile can be determined from simple trigonometric relationships. For instance, if the tilts α of the terrain are measured in seconds of arc at points 1, 2, and 3 (Fig. 2.1) then the subsidence h_4 at point 4 in respect to point 1 can be calculated from:

$$h_4 = \frac{\alpha_1 \times S_1 + \alpha_2 \times S_2 + \alpha_3 \times S_3}{\rho''} \qquad (2.1)$$

or generally for a point n:

$$h_4 = \frac{\sum_{i=1}^{n} \alpha_i S_i}{\rho''} \qquad (2.2)$$

where S_i are distances between i-th and $(i+1)^{th}$ tiltmeters and ρ'' equals 206265" (1 radian in seconds).

The accuracy of the determination of h_i depends on the following factors:

a) sensitivity of the tiltmeters and resolution of the telemetric system

b) density (distances) of the tiltmeter stations and their location along the measured profile

c) type and character of the subsidence .

If we assume that all tiltmeters have approximately the same accuracy (standard error of the tilt measurement) and the distances are errorless (measured with a high accuracy) then the standard error of h_n from equation (2.2) can be calculated from: $\sigma_{h_n} = \frac{\sigma_\alpha}{\rho''} \sqrt{\Sigma s_i^2}$

For instance, if σ_α = 30" and all the distances are equal to S_i = 100 m then:

$$\sigma_{h_4} = \frac{30''}{206265} \sqrt{30\,000} = 25 \text{ mm} .$$

The above example is valid only where the tiltmeters are properly located so that the curvature of subsidence profile between the neighboring tiltmeters may be approximated by straight lines.

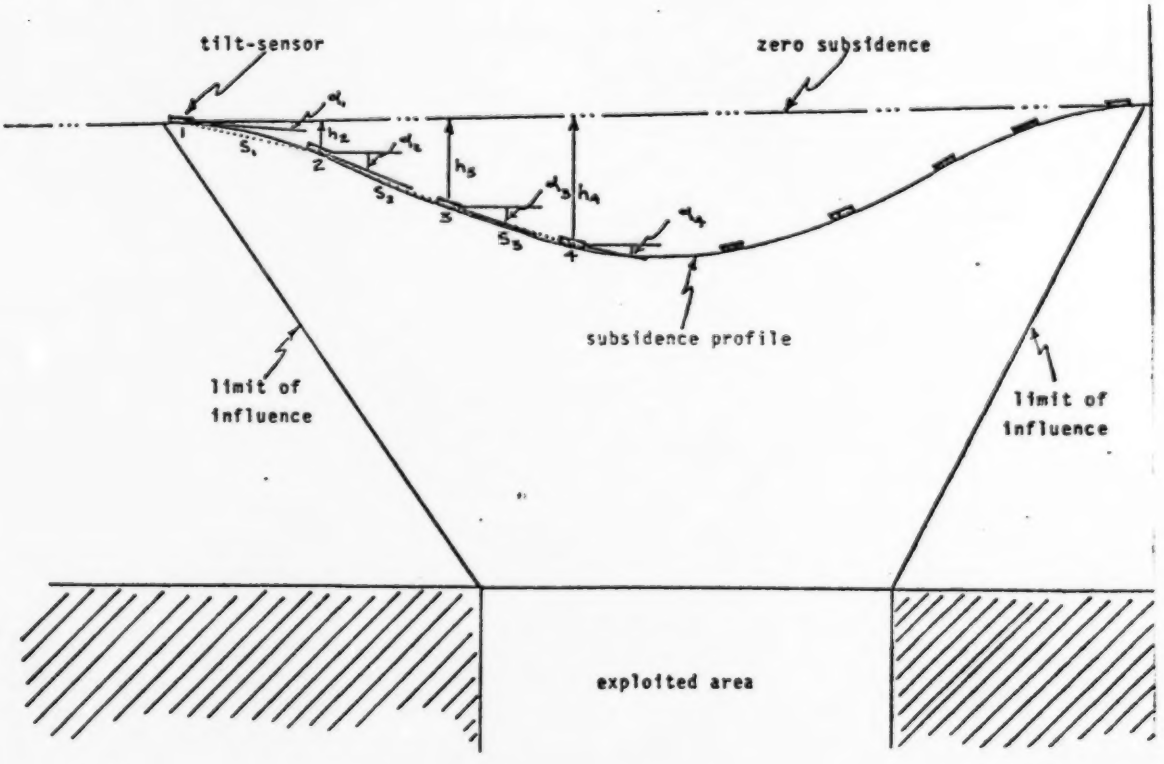

FIGURE 2.1 - Use of tiltmeters in the subsidence determination

It has to be pointed out, that the use of tiltmeters for the development of a prediction theory of the terrain subsidence is, to a large extent, limited to the regular and continuous subsidence conditions as shown in Figure 2.1.

If the mining exploitation would produce abrupt profile changes and breaks of the ground then the information supplied by the tiltmeters could be misleading, or even useless.

It is difficult to predict what type of subsidence will take place in the study area of the Sparwood project but, as it is discussed in Chapter 2.3, there is a good chance that no ground breaks will occur in the area. Then the information supplied by the tiltmeters and the proposed telemetric system may be of a significant importance in gaining more knowledge about the behaviour of the rock masses in these difficult mining and topographic conditions.

2.2 Theory of the Mining Subsidence

Development of the prediction theories for the ground subsidence in mining areas started about 70 years ago in central Europe. Works by Korten [1], Keinhorst [2], Bals [3] or Oberste-Brink [4] may be cited among the oldest publications related to the subject.

Despite several fine theories which give nowadays a good agreement of the prediction with the practical values for specific mining conditions, there is no one general theory which could be successfully applied to any mining and geological condition. There are several schools of thinking; some of them based on mechanical theories of dynamics of elastic bodies, others based on an analogue modelling of the geological strata and, a fair number of so called geometrical

theories, based on empirical data obtained from geodetic measurements performed on real subsidence examples. Kratzsch [5] gives a thorough review of most of the theories being used in practice in different countries.

Some basic findings are common, or differ very little, from one theory to another.

Generally it is accepted [6] that if the depth of the coal deposit is larger than about 100m, a continuous subsidence basin (subsidence trough) is created on the surface. A profile of the subsidence takes the form of a regular exponential bell-shape curve if the rock formations are homogeneous (Figure 2.2).

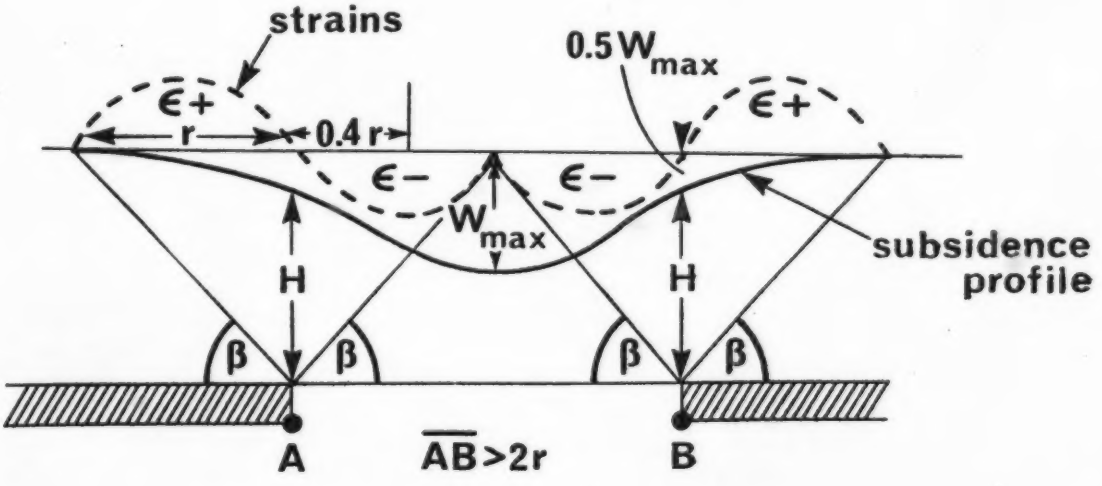

FIGURE 2.2 - Subsidence Basin

Some authors (for instance Szpetkowski [7]) give the minimum depth of the exploitation for obtaining the continuous subsidence profile as equal to

$$H \geqslant 70.W_{max} \qquad (2.3)$$

where W max is the maximum expected subsidence of the surface calculated from:

$$W_{max} = a.g \qquad (2.4)$$

where a is the subsidence coefficient dependent on the exploitation method and g is the thickness of the exploited deposit.

The value of the coefficient a averages:

a = 0.8 for caving method without any pillars

a = 0.5 when using dry stowing

a = 0.2 when using hydraulic back-filling

a = 0.03 for 50% strip and pillar with the hydraulic back-fill.

In order to obtain W max on the surface, a large enough area, equal to the so called critical area, must be exploited. If a larger than critical area is exploited than the bell-shape curve of subsidence becomes flat at the bottom with W max = const. over the flat area.

The subsidence above the edges of the exploitation is equal to approximately 0.5 W max. Usually the points which show only about 1% of W max are taken as being at the limits of the influence of the exploitation. The angle β (Figure 2.2) between the horizontal and the line joining the limiting point with the edge of the exploitation is called a limiting angle.

The value of β is larger for soft and/or elastic rocks than

for a strong strata. Batkiewicz [8] gives the following values:

$\beta = 48^{\circ} \div 66^{\circ}$ for plastic or very broken strata (due to a previous exploitation)

$\beta = 34^{\circ} \div 48^{\circ}$ for a medium strong strata, for instance 50% of shales and 50% of sandstones

$\beta = 23^{\circ} \div 34^{\circ}$ for very strong strata, for instance solid sandstone or limestone.

Some other authors give larger values of β, usually between $55^{\circ} \div 75^{\circ}$.

The radius r of the critical area is calculated from:

$$r = H. \cot \beta \qquad (2.5)$$

Maximum strains ε (Figure 2.2) occur at the points of maximum curvature of the subsidence profile. According to Knothe (see Salustowicz [9]) these points are approximately at distances of 0.4 r from the edges of the exploitation.

The maximum tilt and maximum horizontal displacements occur approximately above the edges of the exploitation.

If a narrow pillar, with a width of $d \leq 0.8$ r is left unexploited within a large exploited area it may cause a very dangerous summation of the strains.

The above general findings apply to horizontal or slightly inclined coal seams (up to about 20° dip). For steeply inclined deposits, up to about 45°, all the deformation perameters are shifted towards the dip by an angle approximately equal to:

$$\chi = 0.7 \alpha \qquad (2.6)$$

where α is the dip angle as shown in Figure 2.3.

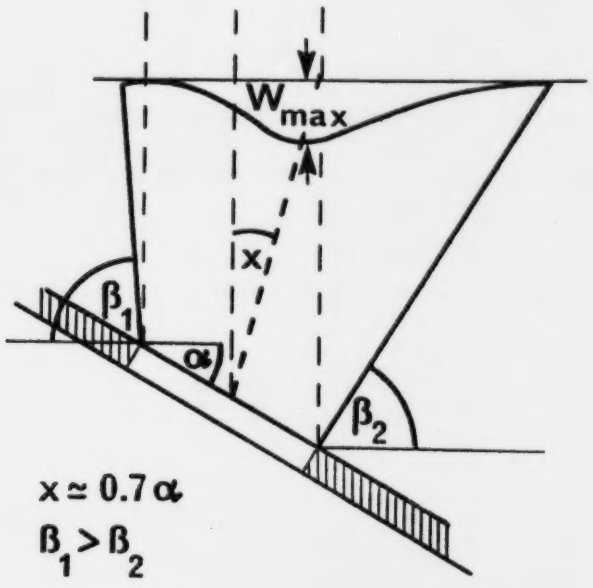

FIGURE 2.3 - Inclined Deposits

Different authors give different theories and equations to describe the shape of the subsidence profile. Usually, the values of the maximum deformations calculated from different theories do not differ more than 10 ÷ 20%. Therefore, for approximate calculations, particularly for "virgin" exploitation areas, one can apply any of the existing theories with an equal probability that the calculated parameters will be wrong anyway.

Knothe's theory, known also as Budryk-Knothe theory, described among others in [9] is one of the simplest to be applied for prediction purposes.

The equation of the subsidence curve for an infinitive semi-plane of horizontal exploitation (Figure 2.4) is given by

$$F(X) = W_i = - \frac{W\ max}{r} \int_X^{\infty} e^{-\pi \frac{s^2}{r^2}} ds \qquad (2.7)$$

from which one can calculate subsidence of any point i (coordinate Xi) at a distance Si from the edge of the exploitation.

From that equation, the maximum curvature is obtained for $X = 0.4\ r$ equal to:

$$K_{max} = \pm \frac{W\ max \sqrt{2\pi} \cdot e^{-\frac{1}{2}}}{r^2} = \pm 1.52 \frac{W\ max}{r^2} \qquad (2.8)$$

The maximum tilt

$$T_{max} = \frac{W\ max}{r} \qquad (2.9)$$

and the maximum strain

$$\varepsilon_{max} \simeq 0.6\ T_{max} . \qquad (2.10)$$

The theory may be applied to any shape of exploitation by subdividing the exploited field into segments of a circle equal to the critical area.

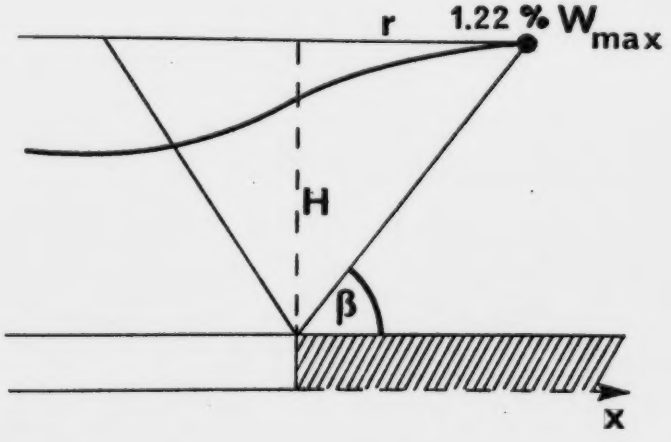

FIGURE 2.4 - Infinite half-plane of exploitation

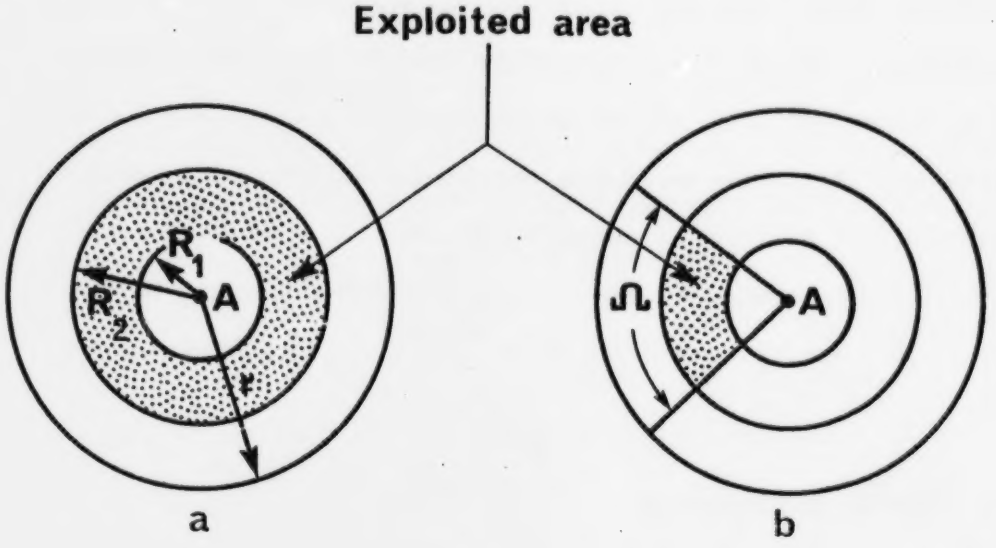

FIGURE 2.5 - Circular Exploitation

For instance, for an exploitation in form of a circular ring (Figure 2.5) with $R_1 < r$ and $R_2 \leq r$ the subsidence in the centre A of the circle is equal to:

$$W_A = W_{max} \int_{R_1}^{R_2} \int_{0}^{2\pi} \frac{1}{r^2} e^{-\frac{\pi}{r^2} R^2} . R.dR.d\phi$$

$$= W_{max} \left(e^{-\frac{\pi}{r^2} R_2^2} - e^{-\frac{\pi}{r^2} R_1^2} \right) \qquad (2.11)$$

If only a portion of the ring is exploited, limited by an angle Ω (Figure 2.5b) then the subsidence at A is equal to:

$$W_{A_\Omega} = W_A \frac{\Omega}{2\pi} \qquad (2.12)$$

where W_A is calculated from (2.11).

This allows to determine subsidences for any point in a very simple semi-graphical way. A circle with radius r is drawn on a tracing paper at a scale equal to the scale of the mining map. The circle is subdivided into circular segments of equal area each. If, for instance, the circle would be subdivided into 8 segments, then the exploitation area covered by one segment would produce the subsidence at the centre A of the circle equal $W_A = \frac{W\ max}{8}$ as it is shown in Figure 2.6.

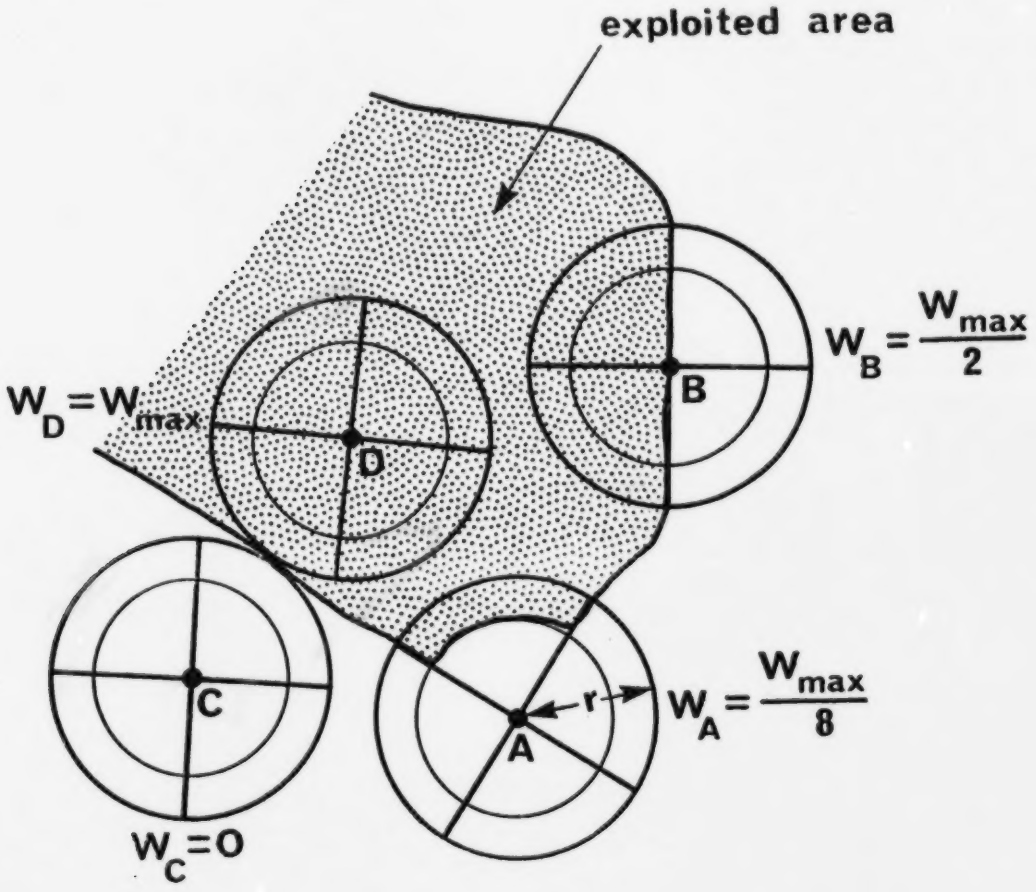

FIGURE 2.6 - Semi-graphical method of the subsidence determination

Now, moving the template circle into point B, we would obtain $W_B = \frac{W\ max}{2}$; at point C, $W_C = 0$; and at point D, $W_D = W\ max$.

The above method of the subsidence determination seems to be fairly adequate for approximate predictions only as it is needed, for instance, by the Consultants in the design of the locations of the tiltmeters at the Sparwood area, as will be discussed in Chapter 2.4.

However, the a-posteriori analysis of the tiltmeter results in the future will require a comparison of the results with some more sophisticated theories of subsidence in order to adopt the best fitting theory to the Sparwood conditions. This will be the next stage of the study which is beyond the present contract.

[1] Korten, D.: "Der Einfluss des Bergbaus auf Strassenbahngleise und seine Bekämpfung". Glückauf 45, 1909.

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[3] Bals, R.: "Beitrag zur Frage der Vorausberechnung bergbaulicher Senkungen. Mitteilungen aus dem Markscheidewesen, 42/43, 1931/32.

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[8] Batkiewicz, W.: "Calculation of the Parameters of the Terrain Deformations due to the Exploitation", (in Polish), Wyd. Slask, Katowice, 1968.

[9] Salustowicz, A.: "Outline of Rock Mechanics (in Polish)", Wydaw-Slask, Katowice, 1965.

2.3 Expected Subsidence in the Study Area

The study area (Figure 2.7) includes a part of the exploitation of the panel 6 of the Kaiser Mines operation. The coal seam which is about 12 m thick and has a dip of about 40° will be extracted in several sub-panels, marked "A", "B", "C" etc. in Figure 2.7. The sub-panels are separated by narrow pillars of about 50 m width.

The thickness of the rock formations above the panel (depth of the coal seam) in the study area varies from about 150 m to 250 m for sub-panel "A", up to 300 m for sub-panel "B" and 300 m to 500 m for the sub-panel "D".

A detailed study of the geology, stratigraphy and strength of the rock formations will be done in Phase II of the project. The preliminary data indicate however, that the rock formations can be classified as medium strong, containing not very solid sandstone and shales. Therefore, the angle of influence β will probably be of the order of 45° to 55° in the profifles along the strike. An earlier study by Y. Fisekci [1] in the neighbouring area gave an unexpected high value of $\beta = 75^{\circ}$. The value was obtained, however, from very approximate measurements of the ground movements.

As a compromise for a preliminary prediction of the ground movements, the Consultants take $\beta = 60^{\circ}$ for further calculations. Therefore, the radii of the critical circles of the influence would be expected as: for sub-panel "A", $r = 200.\cot 60^{\circ} = 115$ m, for sub-panel "B", $r = 145$ m and for "D", $r = 260$ m. As it is seen from Figure 2.7 on which the critical circles are shown, neither sub-panel will produce the maximum subsidence of Wmax which for the given conditions ($a = 0.8$ and $g = 12$ m) could reach the value of Wmax = 10 m.

Only sub-panel "A" may give values close to Wmax. However,

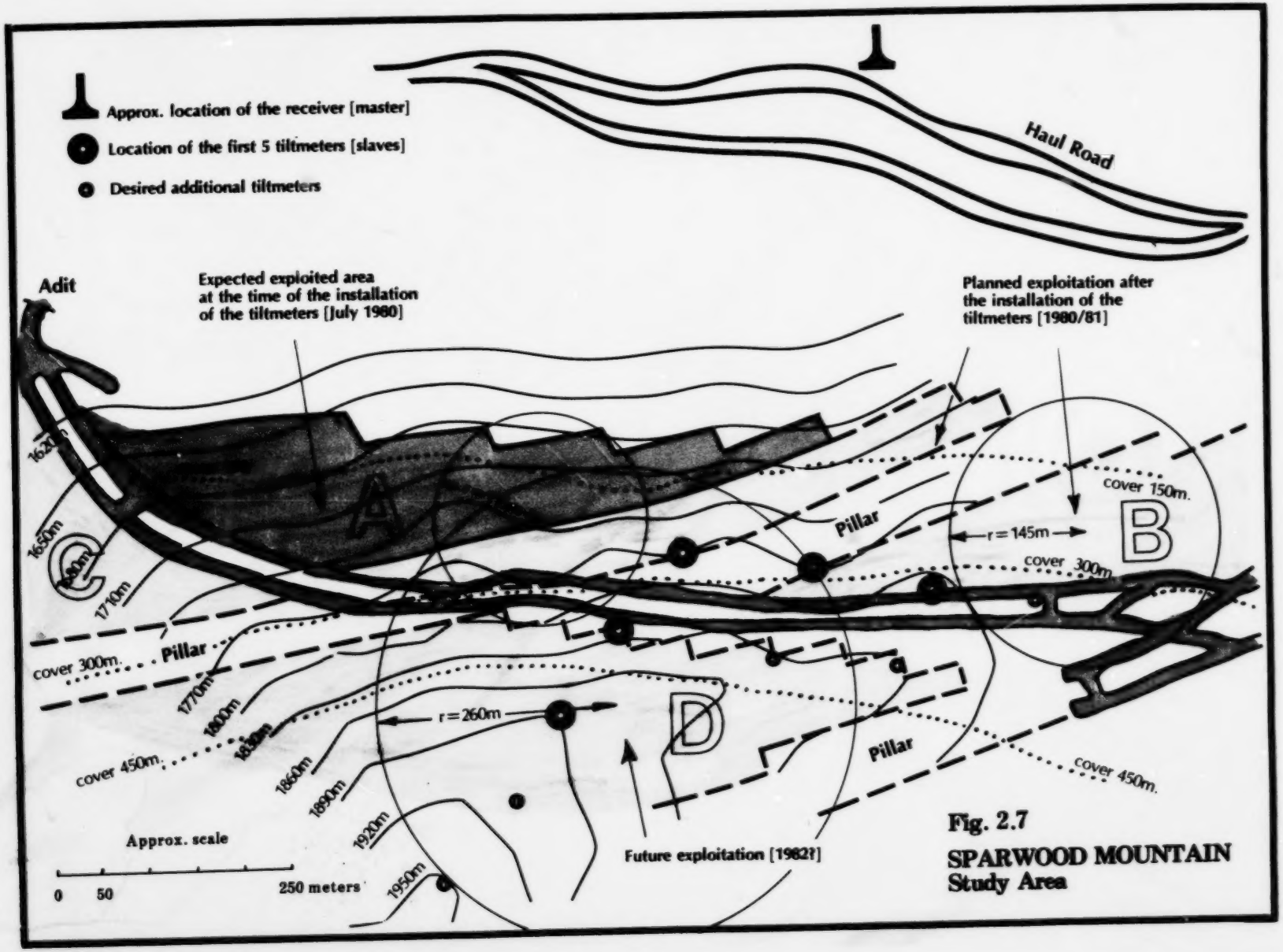


Fig. 2.7
SPARWOOD MOUNTAIN
Study Area

the sub-panel "A", will already be almost entirely exploited (orange colour) by the time of the installation of the telemetric system. The tiltmeters, therefore, will be affected only partially by the exploitation of the sub-panel "A". The sub-panels "B" and "D" can produce subsidence of about 40% of Wmax each, which means about 4 metres.

The maximum tilts, (equat.2.9) for the sub-panels "A", "B" and "D" will then be expected to be: 86 mm/m, 28 mm/m and 15 mm/m respectively, which in angular units become equal to: 5^{o}, 1.6^{o} and 0.9^{o}.

The maximum strains (equat.2.10) can reach the values: 52 mm/m, 17 mm/m and 9 mm/m for sub-panels "A", "B" and "D" respectively. The value of 52 mm/m is very large and, therefore, one can expect that the sub-panel "A" will produce breaks on the surface. The sub-panels "B" and "D" will, hopefully produce a continuous subsidence profile particularly in the upper part of the mountain slope. However, the presence of the narrow pillars between the sub-panels and the fact, that the individual sub-panels do not reach the dimensions of the critical areas complicate the prediction of the deformations as well as of the future interpretation of the results obtained from the tiltmeter measurements. The very steep topography and large dip of the coal seam add uncertainties to the application of any existing subsidence theory.

Practically, therefore, the Consultants have to admit, that they are unable to predict the behaviour of the mountain slope in the study area except for some guesses outlined above.

This emphasizes the need for the design of a monitoring system which would give empirical information on the behaviour of the rock masses under these difficult conditions.

REFERENCES:

[1] Fisekci, M. Y.: - "Subsidence Studies During Working of a Steeply Inclined Dipping Coal Seam", - Report ERP/MRL 75-84 CANMET, 1975.

2.4 Design of the Location of Tiltmeters (Slave Stations).

The exploitation in panel 6 is supposed to start in sub-panel "A" (Figure 2.7) by the end of this year or early in 1980. It is very unfortunate, that because due to snow coverage until mid June, the monitoring system cannot be installed earlier than about mid July. By that time a major part of sub-panel "A" will probably be exploited as shown in orange colour in Figure 2.7. The monitoring system will therefore not detect the initial influence of the exploitation which, by that time may already reach the surface. It is, however, desired to have one, or two tiltmeters installed within the expected radius 'r' of the influence of the already exploited area in the upper part of the mountain. The expected values of 'r' were given in the previous section.

Due to the limited funds for this project, the Consultants are permitted to install only a total of five tiltmeters. It is planned to use bi-axial type tiltmeters in order to obtain the maximum possible amount of information from these very few monitoring (also called Slave) stations.

The remaining three tiltmeters should be installed beyond the influence of the already exploited area so that they could monitor the epoch of time when the influence of the new exploitation (remaining part of block A and sub-panels B and D) will reach the surface. Therefore their location should be at distances approximately equal to the estimated values of 'r' from the limits of the previous exploitation.

The tiltmeters should also be located in areas of the expected maximum tilts.

Another condition is, that the slave stations should, if possible, be visible from the haul road where either the receiving (master)

station or the relais station will be installed.

Taking the above conditions into consideration, compromised locations for the five tiltmeters have been designed or shown in Figure 2.7. It is, of course, only a preliminary design, because the final design will have to be done just prior to installation in order to have the actual information on the exploited area.

The tiltmeters, if installed approximately according to the design shown, could remain in the same place for about three years because they can monitor the exploitation in sub-panels B and D. Later on, two or three tiltmeters should be moved to new locations depending on the progress of the exploitation.

It would be utterly desirable to have more than five slave stations on the slope in order to support any prediction theory on the basis of the telemetric system. At least five additional sensors, as shown in Figure 2.7 should be installed. This, however, would exceed the projected cost of the project by about $30,000.

2.5 Selection and Testing of Tiltmeters

After a comprehensive literature review of available tiltmeters, the Consultants focussed their investigation on two types of tiltmeters, namely,

-- Electrolytic Tiltmeter by Slope Indicator Co. (SINCO)

-- Servo-accellerometer tiltmeter by Terra Technology.

The operational ranges of both types of tiltmeters satisfy the conditions for the project at hand. The SINCO model is a biaxial tiltmeter, while Terra produces both uni- and biaxial instruments. Because of the difficult geological and topographic conditions in Sparwood, the

Consultants consider it imperative to use biaxial sensors. One unit each from SINCO and Terra was obtained on loan for laboratory testing. The purpose of the tests was to monitor their behaviour for different tilts, different temperatures, covering the range specified in the contract, and under the influence of minor shock and vibrations.

Both Sensors were mounted onto a 3 m long bar, which was held at a solid support on one end and which could be raised and lowered at the other end with the aid of a micrometer screw with a least count of 10 um. The tiltmeters were enclosed in a plastic bubble for temperature control and fitted with a precision temperature sensor which provided continuous temperature reading displays to 0.1^{o}C.

The following test series were conducted:

1) Repeatability of the tiltmeter readings at a fixed temperature.

2) Repeatability under shock influence.

3) Repeatability under vibration influence.

4) Repeatability of tilt readings at temperatures between +8 and +34^{o}C.

5) Repeatability of tilt readings at low temperatures (-30^{o}C to 0^{o}C).

6) Tiltmeter behaviour over whole temperature range (-30^{o}C to +30^{o}C).

Rather than repeating the details given in the Progress Report for June, the main findings are summarized:

— Test Series 1: Both sensors produced excellent repeatability, with the Terra sensor showing a clearly linear behaviour, while the SINCO sensor did not behave quite linearly (see Figure 2.8).

— Test Series 2: No change from the behaviour reported for test series 1.

-- Test Series 3: No change from behaviour reported for test series 1.

-- Test Series 4: The characteristic behaviour remained as in test series 1, although there are some small changes which can easily be handled by calibration.

-- Test Series 5: The SINCO unit required a long time to react to tilt changes, but did so as expected. The Terra unit malfunctioned at -17°C. Up until then, its behaviour remained linear.

-- Test Series 6: The change of the SINCO readings for different temperatures was continuous and could be properly monitored. The Terra unit remained erroneous after the initial malfunctioning.

Since the Terra tiltmeter has much smaller dimensions and less mass, (which would greatly reduce packaging problems and costs), and since its behaviour is linear when it functions properly, it would be desirable to utilize it, provided the low temperature operation can be assured. Communications with Terra Technology (see also Appendix I) revealed, that the unit sppplied had not been tested for low temperatures and that it was filled with high viscosity dampening fluid as used for higher temperatures. The company has produced low temperature units operating at -70°C and is willing to provide units with guaranteed proper functioning at the required temperature range of -25°C to + 40°C.

Another unit has already been shipped by Terra Technology for additional testing at low temperatures. If it performs well, the Consultants would like to utilize this type of tiltmeter because of its truly linear behaviour and very favourable dimensions (mounted in a

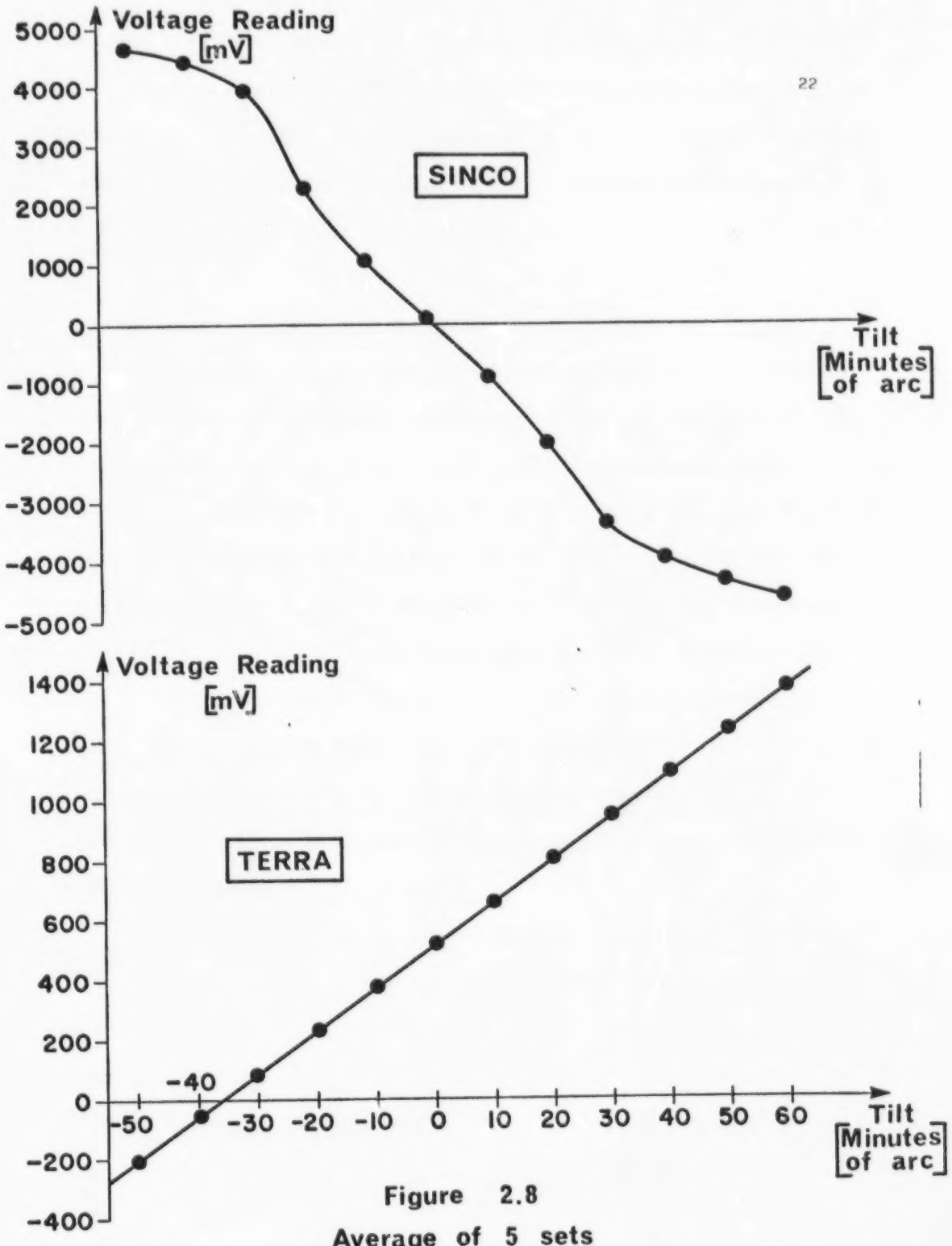


Figure 2.8

Average of 5 sets
at room temp (22.6 ÷ 22.2 C)

vertical steel pipe ≈ 20 cm long with 2.5 cm diameter).

Otherwise, the SINCO unit has to be used, even though it is bulky (box 10 x 10 x 20 cm^3) and behaves in a non-linear fashion. Both these disadvantages can be overcome by increased efforts in packaging respectively calibration.

2.6 Expected Accuracy of the Telemetry Monitoring System.

As mentioned in Chapter 2.1, the accuracy of the subsidence determination with tiltmeters will mainly depend on the type of the ground deformation. If abrupt changes of the subsidence profile or ground breaks will occur on the surface, then the tiltmeters will signal only that "something" has happened at the slave station without any possibility, however, for quantitative evaluation of the tiltmeter indications. In that situation, the accuracy of the tiltmeter indications will be of no importance. Nevertheless, even in such situations, the signal from the slave station that "something" happened will also be a valuable information for the interpreters of the influence of the exploitation. Therefore, even in the worst case, the presence of the tiltmeters may prove to be useful.

It is hoped, that the area selected for the installation of the tiltmeters will be subjected to a resonably regular subsidence. Then, the indications of the tiltmeters will supply information similar to the trigonometric levelling when using the geodetic surveying method as discussed in 2.1. The accuracy of the subsidence determination will depend mainly on the accuracy of the detection of the tilt angles at the Slave stations.

The accuracy of the tilt measurement depends on two factors:

1) resolution accuracy of the receiving station and,

2) accuracy of the tiltmeter indirections.

The resolution of the receiver will be about 0.4% of the total expected range of the tilt because the receiver will have a capability of accepting information coded into 8 bits ($1/_{255} \approx 0.4\%$).

It is expected to have maximum tilts (in the sub-panels B and D) in the order of 1°. This would mean that the limits of the resolution would produce errors in the readout of the tilt angle in the order of $1^{\circ}/_{255} \approx 14"$. For the average planned distances of about 120 m between the tiltmeters, the error of 14" would produce an error $\varepsilon_{\Delta h}$ in the relative subsidence determination of only:

$$\varepsilon_{\Delta h} = \frac{14" \times 120 \text{ m}}{9"} = 8 \text{ mm}$$

So, even for the tilt of twice that amount (2°), the error would only be 16 mm; which is of the same order as one could expect to obtain from conventional trigonometric levelling when using EDM and vertical angle measurement from stations located, for instance, somewhere on the haul road.

The selected tiltmeters (see previous section) have a sensitivity of a few seconds in the tilt determination. The reading is, however, temperature dependent. For instance, the SINCO tiltmeter is supposed to give the accuracy of the tilt determination according to the formula:

$$\varepsilon_{\alpha} = \pm \text{ (0.05\% reading + 0.05\% range) per } 1^{\circ}\text{F}$$

The above formula may be translated into:

$$\varepsilon_{\alpha} = \pm \left(\frac{\alpha"}{2000} + 3.6" \right) \frac{9}{5} \quad \Delta t^{\circ}\text{C}$$

if a tiltmeter with 2° range is used, where α is the recorded tilt

in seconds of arc, and $\Delta t^{\circ}C$ is the difference in $^{\circ}C$ of the actual temperature from the calibration temperature.

For instance, in extreme conditions, for a tilt of 2° and $\Delta t = 40^{\circ}C$, the error would be: 518" !

Therefore, the tiltmeters must be calibrated for different temperatures, and the readouts must be corrected. It means, that temperature sensors must be included in the Slave stations and each tiltmeter will have to be carefully calibrated in the laboratory before its installation.

It can be expected that the accuracy of the temperature determination will be better than $1^{\circ}C$. Then the corrected tilt determination for the above conditions should not have an error ε_{α} larger than 13".

The Terra Technology servo-accellerometer type tiltmeter seems to be much easier for the precise temperature calibration (see Appendix I) and, therefore, its accuracy is expected to be even better than 13" for the extreme conditions.

In conclusion, one can expect, that maximum errors of the tilt determination are not larger than the resolution of the receiver, which means 28" for a maximum tilt of 2°.

One should point out, however, that the final accuracy of the subsidence determination will heavily depend on the quality of the installation of the Slave stations, so that one could be sure that the detected tilt is the tilt of the geological strata and not only a movement of the Slave station itself due to improper anchoring of the instrumentation in the bedrock. For this reason, a comparatively generous amount of labour hours has been predicted in Phase II for the

installation of the monitoring instrumentation. However, these hours may be critical for the success of the whole project.

3. PRELIMINARY DESIGN OF THE TELEMETRY/MONITORING SYSTEM

This chapter provides a summary of the investigations into the design of the Monitor/Telemetry system. It outlines the underlying ideas leading to the proposed design emphasizing reasons for trade-offs and indicating advantages and limits of the resultant system. For more elaborate descriptions the reader is referred to the monthly reports.

3.1 Statement of The Problem

A data acquisition system is required which offers monitoring and data analysis capabilities of sensor information. At various locations in the field a group of sensors is connected to Slave units. The inaccessible mountaineous area calls for wireless communication between the remote battery powered Slave units at the sensors' locations and a central Master unit. The latter is to be accessible year-round and requires hydro-power and public telephone network access.

The Master represents the telemetry controller and establishes the User interface of the telemetry system. It is to handle the acquisition of sensor data from the Slaves and to provide data storage and data analysis capabilities. Access to the public telephone network is to be provided to allow for remote control of the Master's functions.

The monitoring/telemetry system is to operate for a period of one year without battery replacement at operating temperatures in the range of $-25^{o}C...+40^{o}C$ and $10^{o}C...+40^{o}C$ for Slaves and Master, respectively.

The blockdiagram of a telemetry system satisfying the above requirements is illustrated in Figure 3.1.

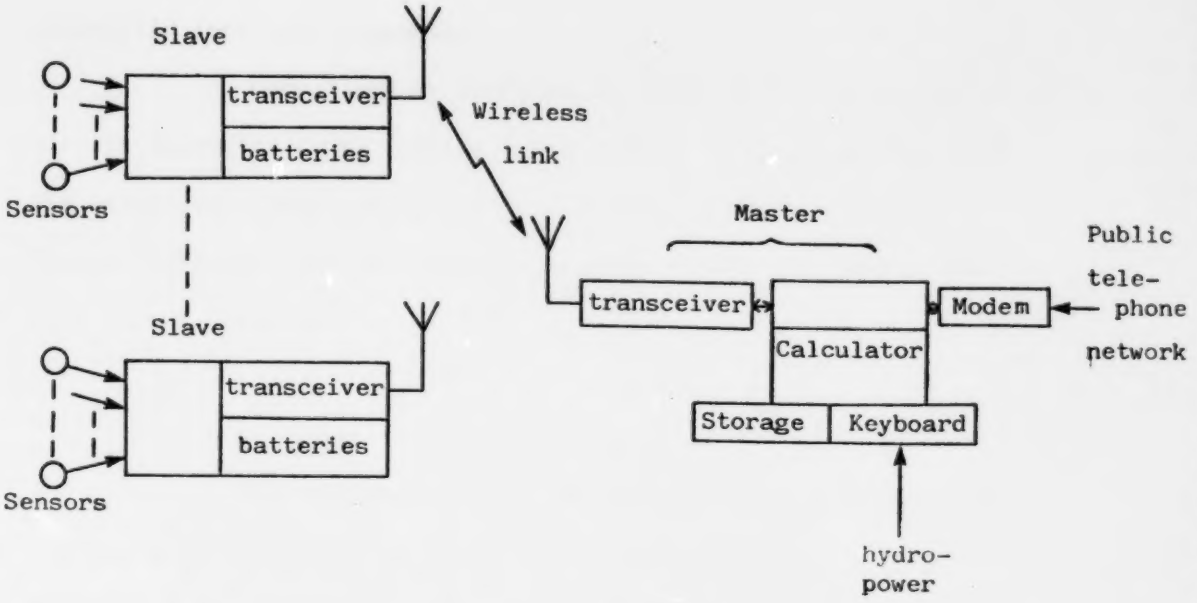


FIGURE 3.1 - Blockdiagram of the Monitoring/ Telemetry System.

3.2 Approach and Solution

The monitoring/telemetry system is designed as a general purpose data acquisition system with flexibility and future expansion capability in mind. It derives its versatility and power from the utilization of latest microprocessor technology and data communication principles. As such, the hardware complexity is minimized and the control software determines the operational features of the system.

3.2.1 Reporting and Addressing

Each Slave provides the Master with sensor data when called for. The interrogation method, whereby the Master requests data from a Slave, was compared with the periodic reporting method of Slaves. The first technique was selected as it permits selective scanning of the Slaves providing for responsiveness to abnormal conditions, trend analysis capability and quick hardware failure

diagnostic (see April Report).

Each Slave is individually addressable by the Master via the telemetry link. Analog versus digital addressing was studied. The latter was found superior, because it has an inherent noise insensitivity and can accommodate a larger number of Slaves (see June Report, Section 4).

3.2.2 Slave

The telemetry system accommodates up to 256 individual Slaves, each monitoring up to four data points (sensors). For the Sparwood project, three points will be used for biaxial inclination information (2 points) and temperature monitoring (1 point) with one data point still available (see May Report, Section 5, and June Report, Section 3).

The Slave's electronic circuitry must provide reliable operation in an unmanned environment under adverse conditions. To combat electric noise and maintain accuracy of data, the sensor signals are digitized, followed by digital processing throughout (see May Report).

The sophistication required of the Slave's operational procedures calls for a microprocessor based unit. Flexibility and intelligence is achieved at minimal hardware expense by providing all functions under software control. A compromise affecting hardware complexity, intelligence and energy consumption had to be found (see June Report, Section 4). Figure 3.2 illustrates the blockdiagram of the Slave's electronic circuitry. The Microprocessor Control Unit governs the operation of the Slave. It receives commands from the Master via the Telemetry Module, initiates collection of sensor data

from the Data Acquisition Module, and transfers collected data to the Telemetry Module for transmission to the Master. The Power Distribution Unit is under control of the processor which powers up and down the modules as required.

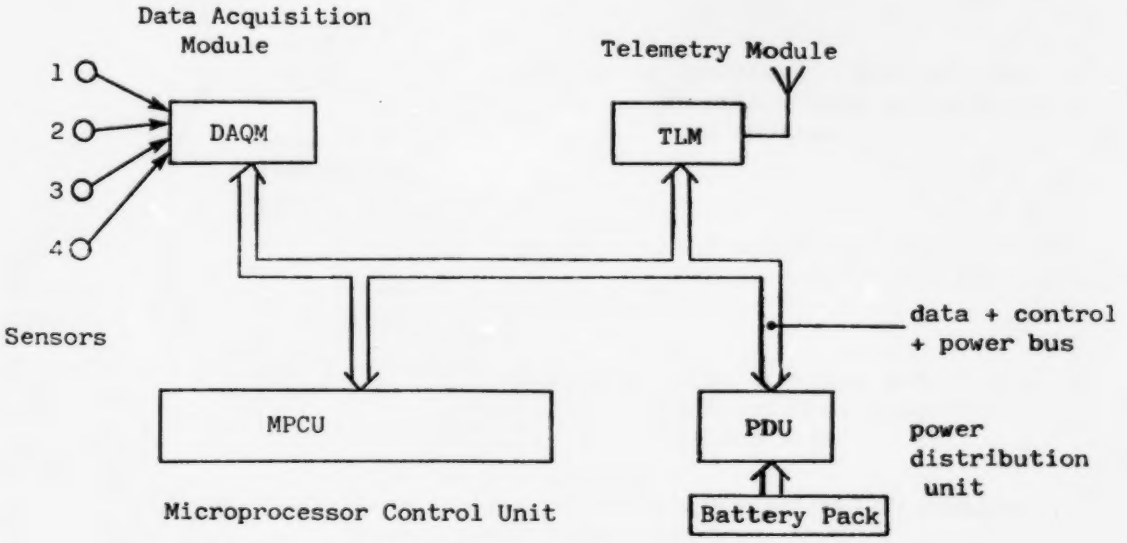
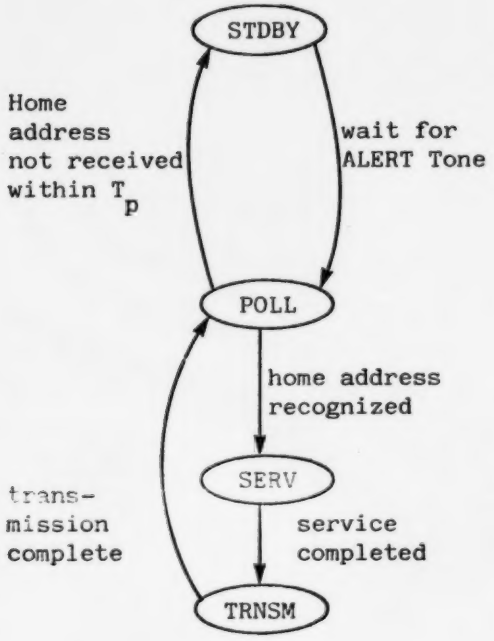


FIGURE 3.2 - Blockdiagram of Slave's Electronic Circuitry

As each Slave is battery powered, minimization of energy consumption is of prime concern. Minimization of hardware complexity contributes to this as well as minimization of power-up periods of the modules of the Slave. To achieve this objective, the Slave is operated in a manner as shown by the state diagram in Figure 3.3. In Stand-by mode only the Receiver and Alert Tone Decoder of the Telemetry Module are powered up (see June Report, Sect. 4 c). Upon reception of an Alert Tone from the Master, all Slaves enter the active state (Poll mode) expecting a subsequent address. The selected Slave recognizes its home address and remains in the active state whereas all other Slaves return to the Stand-By mode. Reception and execution of the requested command (log data, test, transmit data) follow this addressing



Standby: Receiver and Alert Tone Decoder Active

Addressing (polling): MPCU active, as well, check for Slave's home address

Service: DAQM active as well, receive command and service it

Transmit: DAQM inactive and TLM activated to transmit logged data

FIGURE 3.3 - State Diagram of Slave's Operational Procedures, (see Figure 3.4 for legend).

procedure within the Service state. An elaborate discussion can be found in the June Report, Sect. 4 c-e.

The control software determines the operational features of the Slave. Figure 3.4 shows the modular architecture of the software as related to the component of the diagram in Figure 3.2. The Debug Monitor is instrumental in maintenance and problem debugging of the control software. A Self-Test function checks the Slave's hardware prior to every data collection event, and permits extensive maintenance to diagnose upcoming hardward problems.

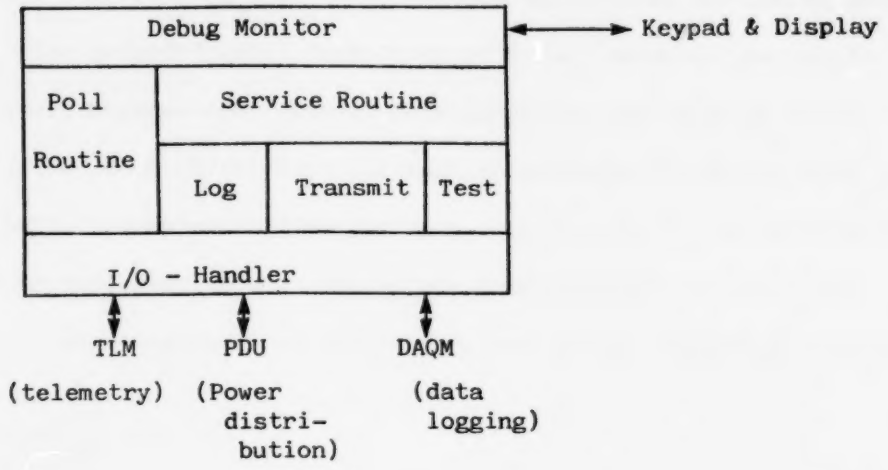


FIGURE 3.4 - Modular Architecture Of Slave's Control Software.

3.2.3 Telemetry Principles

The interrogation method calls for a bidirectional data link between Master and Slaves which offers the required interactive communication.

Straight analog modulation was compared with digital modulation. The latter was selected for its inherent noise insensitivity and provision for ready incorporation of identification information within data records, (see April Report). Data interchange takes place in digital form under the FSK scheme. The information flow follows the widely used character-oriented asynchronous ASCII line code and line protocol to facilitate maintenance and trouble shooting. Each message is protected by a parity bit per character and a longitudinal redundancy check character (LRC) per message block (see June Report, Sect. 4). Transmission-error detection and recovery procedures (i.e. retransmission

request) are incorporated into the Slave and Master thus achieving data security. The selected octal formatting of binary data is the result of a trade-off between most compact data structure and ease of character handling. The form of relevant information messages is chosen such as to minimize transmission time yet to permit successful error-recovery (see June Report, Sect. 4 d). Incomplete transmissions are detected by time-out, avoiding synchronization problems during intercommunication periods.

3.2.4 Master

The Master unit represents the central data acquisition controller and serves as user interface. The intelligence required to successfully handle the control functions call for a computer based Master unit. As many of the software modules are User oriented, a desk calculator is used (see June Report, Sect. 5).

The blockdiagram in Figure 3.5 shows the components of the Master. The control unit originates Slave interrogation and receives requested data via the Telemetry Module. All data processing tasks are carried out by the desk calculator under program control. Manual intervention is exercised through the calculator's keyboard, and data are stored on the cassette unit. The Public Network Access unit interfaces to the common carrier telephone network through an Automatic-Answer Data Modern. Control over the data acquisition process and subsequent data analysis can be exercised remotely through CANMET's HP9845 or HP3000 system or similar computer systems (Kaiser, UNB Fredericton). Data communication takes place under the standard asynchronous ASCII code and line protocol at 300 baud. The User is to provide the

required hardware and software beyond the scope of the Master unit (see June Report, Sect. 5b).

Basic control software handles the interrogation of Slaves, receiption of requested data as well as error recovery, Self-test analysis, non-linearity and temperature compensation of sensor data. Higher-level data processing programs operating upon the sensor data depend on the User application. As they are coded in the calculator's high-level language (reverse polish), they are easy to design, code and debug. User programs can readily be added or deleted from the User's application program package. Figure 3.6 shows the architecture of the Master's support software (see June Report, Sect. 5d).

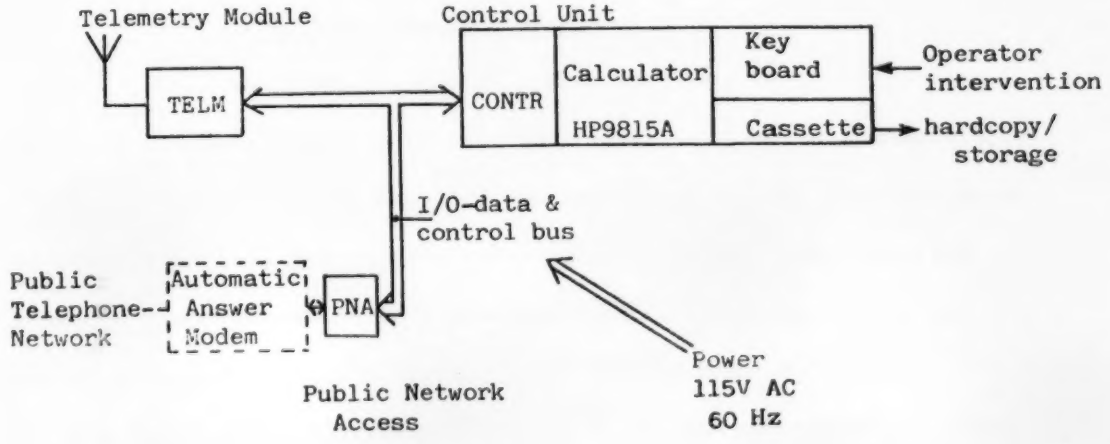


FIGURE 3.5 - Blockdiagram of Master Unit

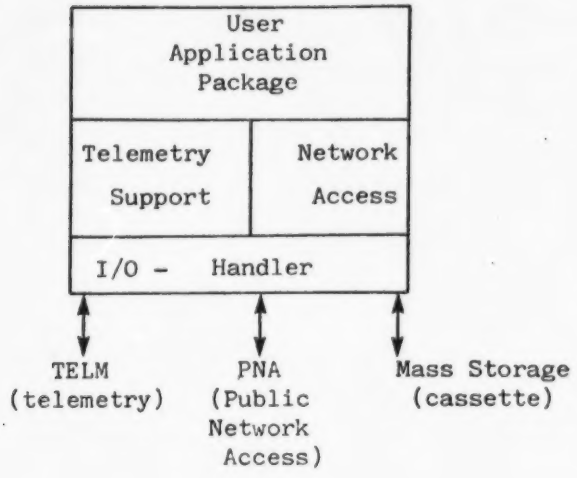


FIGURE 3.6 - Architecture of Software For Master Support

3.2.5 RF-Transmission Analysis

The radio-telemetry system operates in the VHF-range (approx. 150 MHz) requiring direct view from receiver to transmitter. Non-directional antennas are used for the Slaves on the mountain slope to avoid wind-load and constructional difficulties. The resulting possible disturbance due to reflected signals in the mountains was analysed (see June Report, Sect. 7) and showed a maximal time spread of $\Delta T_R \lesssim 20$ μsec (ground reflections). Direct and reflected signal fall into the same bit slot of digital FSK modulation for a bit period of $T_B > 40$ μsec, i.e. a bit rate of $f_B < 25$ K Baud. The recommended bit rate of 300 Hz is well within this range.

The modulation frequencies for the FSK modulation are chosen to be the standard originate and answer frequencies. The Alert signals issued by Master and Slave are selected for least interference with the FSK signals as 1800 Hz and 900 Hz, respectively. Figure 3.7

shows the blockdiagram of the Information exchange scheme including the Public Telephone Network Access (voice grade band 300-3000 Hz), see June Report, Sect. 7.

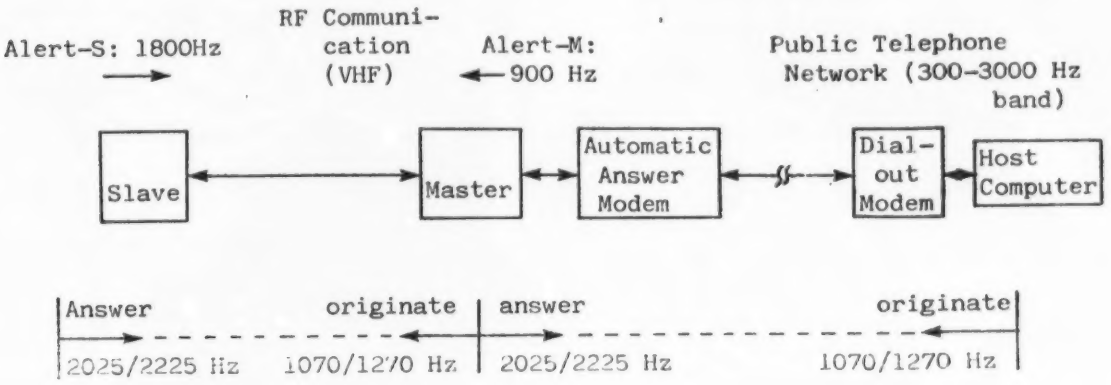


FIGURE 3.7 - Information Exchange Scheme

3.2.6 Relais Station

The visit to Sparwood indicated a possible need for a Relais Station if direct view between Master and Slaves does not exist. The site plot in Figure 3.8 shows this situation where the view from point A to C is blocked by a hill.

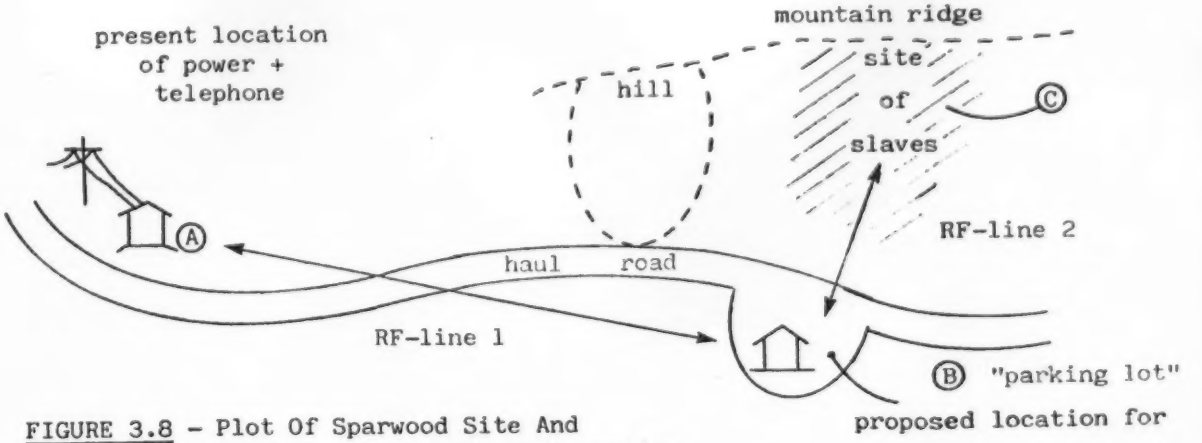


FIGURE 3.8 - Plot Of Sparwood Site And Possible Telemetry Configurations.

It is strongly suggested to extend the hydro power and telephone line from point A to point B, the proposed location of the Master. In this instance the Relais Station is not required, causing no additional cost and achieving enhanced reliability.

Other situations are investigated and discussed in detail in the June Report, Sect. 6. This report also outlines the hardware configuration, operational principles and the software architecture of the Relais Station.

4. INVESTIGATION ON THE APPLICATION OF PHOTOGRAMMETRY

Photogrammetry provides an instantaneous, complete and remote recording of an object. Applied to the project at hand, this means that the whole study area can be covered. It is therefore possible to evaluate either the whole slope or certain areas of interest only. If subsidence phenomena appear in unexpected locations, one can go back to the photographic record and reevaluate and thus recover information which otherwise would have been lost. On the other hand, there are limitations on the timing of the photogrammetric missions as well as on the accuracy that can be achieved. Due to the climatic conditions in the Sparwood area, photography would be restricted to the summer months after the snow has melted. Since there is only a sparse vegetation cover on the study slope, the actual timing within the snow free period appears not to be critical.

4.1 Terrestial Photogrammetry

Although this option seems to be well suited for mountainous terrain, the Consultants feel that it has to be discarded in this case. In order to obtain useful coverage, the photo base would have to be located on the opposite ridge. With the width of the Sparwood valley, this would lead to rather small image scales, even with normal angle cameras, and thus result in a low accuracy survey. The use of a special camera with an extremely large focal length may somewhat ease the problem, would however be economically unfeasible because of extremely high equipment rental cost, not to mention the difficulties of obtaining such an astronomical camera.

4.2 Aerial Photogrammetry

Since accuracy is a direct function of the image scale, it is desirable to have as large a photo scale as possible. Considering a standard aerial camera (23 x 23 cm^2 format, 15 cm focal length), an approximate photo scale of 1:7000 appears to be the best. At this scale the slope can be covered in one strip, resulting in one or two stereo models. This scale would allow for a small safety factor during flight execution, which at an altitude of about 1000 m above terrain (centre of slope) should not pose any practical problems.

Ground control should be placed, targetted, and coordinated on the ridge and below the exploitation area near the haul road, which should not generate many problems. It would be desirable to use a reseau camera for highest accuracy and to have double coverage. This, in conjunction with a high precision analytical photogrammetric evaluation instrument (e.g. precision comparator for point measurements; analytical plotter for profiles) provides absolute accuracies of 7 + 10μm in the photo scale, which means 5 to 8 cm on the ground.

4.3 Evaluation

It should be clearly stated that this accuracy can only be achieved when using an analytical evaluation, i.e. precision stereo comparator for point measurements, analytical plotter for profiles. Photogrammetric plotters, designed for topographical mapping cannot handle corrections for remaining systematic effects of camera calibration or atmospheric influences. Therefore an accuracy loss by a factor 2 to 3 would have to be expected when using conventional plotting equipment and techniques.

The Consultants have ready access to analytical equipment (Zeiss Precision Stereo Comparator PSK and OMI Analytical Plotter APC-2) as well as the necessary software to incorporate additional parameters for the mentioned systematic effects. They are thus in a position to fully utilize the information inherent in the photography.

For the project at hand, it appears to be most useful to have photography taken after the melting period in 1980, 1981, 1982, with the first mission being flown after installation of the telemetric system, as it is anticipated that ground control will be provided at that time. The evaluation would consist of the measurement of selected points, as well as of the plotting of a few significant profiles across the slope.

4.4 Cost Estimates

Although this is beyond the scope of the present contract, a rough cost estimate is provided.

1)	Ground control survey in local coordinate system, performed in connection with telemetry installation:	
	6 points at $300/point =	$ 1,800.00
	(Note: a separate survey would cost much more)	
2)	Photographic mission (estimated)	$ 2,000.00
3)	Analytical evaluation for two models: 30 hrs. equipment rental plus operator at $30/hr =	$ 900.00
4)	Incidentals =	$ 300.00
	Total cost for first coverage: (estimated)	$ 5,000.00

For the 2nd and 3rd flights, the cost of the ground control survey can be omitted, which reduces the cost to $3,200 each, thus leading to a grand total of $11,400.00 (estimated) for the project.

5. REASSESSMENT OF PHASE II

5.1 Cost of the Project

Based on the results of the investigations carried out in Phase I, the following costs are projected for Phase II:

1) Direct labour - at fixed hourly rates -- (see Appendix II for details)

a)	W. Faig for estimated	237.5	hrs @	$27.43/hr	$ 6,514.63
b)	A. Chrzanowski	" 183	hrs @	$36.00/hr	6,588.00
c)	B. Kurz	" 324	hrs @	$29.68/hr	9,616.32
d)	A. Makosinski	" 330	hrs @	$26.50/hr	8,745.00
					$31,463.95

2) Subcontract .....

a) Professionals

E. Hale for estimated 22 hrs @ $35.00/hr $ 770.00

b) Non-professional

(Mechanical Workshop and sensor calibration: estimated 25 + man days @ $56.00/d $ 1,400.00

3) Direct Charges .....

(see Appendix III for details)

a)	5 tiltmeters @ $1957.20	est.	$ 9,786.00
b)	1 Master/controller	est.	7,325.43
c)	6 Slaves @ $2097.20 (including parts and batteries)	est.	12,583.20
d)	relais station	est.	4,568.38
e)	freight and travel	est.	6,080.00
f)	long distance communication	est.	400.00
g)	report printing and duplication	est.	450.00

4) Ceiling fee 10% of direct labour 3,363.40

$78,190.36

+ Cost of Phase I 14,108.06

+ Fee of 10% of Direct Labour 1,347.73

Total $93,646.15

NOTE: If the relais station is not required, the total cost would be reduced by $4,568.38.

5.2 Comments

The reassessed cost does not include:

1) Surveying services (location of tiltmeters) during the installation at Sparwood.

2) Helpers (external labour) during the installation.

Items 1 and 2 are to be supplied by the Scientific Authority in co-operation with the Kaiser Mine, as agreed upon with Dr. Y. Fisekci during the visit to Sparwood.

3) Rental of drilling-, digging-, and other equipment needed for the installation.

4) Construction of a hut or shelter for the Master station and/or the relais station if needed. Items 3 and 4 are to be supplied by Scientific Authority as agreed with Dr. Y. Fisekci.

5) Telephone connections to local computer facilities and appropriate software for the user system. This is to be supplied by the user.

6) Emergency travel expenses of repair of the system is needed (see proposed warranty terms).

The cost of Phase II increased mainly by:

1) Use of the biaxial tiltmeters (a necessity arising from the evaluation of the expected subsidence); an increase of about $5,000.

2) Prices of components increased about 10% since last year and the Canadian Dollar value dropped about 3%.

3) More time needed for the installation of the system than

it had been estimated due to very difficult terrain conditions.

NOTE: The hourly rates for the Consultants remain the same as a year ago despite inflation of about 10%.

The cost of the Phase II can be decreased by $4,568.38 if the relais station will be not needed. It is very desirable that the Kaiser Mine would be persuaded to extend the power line (see Conclusions and Recommendations). A preliminary agreement has been reached during the Sparwood visit.

5.3 Warranty Terms

1) The Consultants will not be responsible if a malfunctioning of the system would arise due to an Act of God (avalanche, lightning,etc.) due to vandalism or wild animals, or due to misuse of the system by the users.

2) The present statement in the contract that only 10% of the system may fail at any given time is unrealistic, because if any component of the Master or relais station would fail, the whole system would not work. Even the temporary loss of one sensor would mean 20% with only five sensors.

Therefore, this statement should be changed such that the system is to function for at least 90% of the warranty time.

3) In the case of a failure of one of the components the Consultants will not be responsible for a period of time larger than the warranty time given by the manufacturer of the component.

4) If the system will fail to work due to the Consultants' negligence, then the Consultants will cover the cost of the

labour connected with repair and the Crown will cover the travel expenses, if needed, as agreed verbally with Mr. Chambers at the time of signing the contract.

6. CONCLUSIONS AND RECOMMENDATIONS

1) It is very difficult to predict at the present time the behaviour of the rock masses in the study area.

2) The telemetry monitoring system with the tiltmeters appears to be the only feasible solution for year-round monitoring.

It is strongly recommended to use additional monitoring methods during the summer months, namely,

a) to continue the geodetic surveying method as initiated by the Scientific Authority,

b) to initiate the photogrammetric survey (once or twice/year) as designed by the Consultants. The Consultants have the capacity to perform the photogrammetric survey on a basis of a separate contract at a cost of $5,000 per one survey.

3) The Scientific Authority should use all their abilities to supply power and telephone lines to the project site of the Master station and to connect the system to the telecommunication network. This would give the following advantages:

a) lower cost of the Phase II (relais station not needed),

b) reliability of the telemetry system significantly increased,

c) no need for year-round servicing (charge of batteries) at the relais station,

d) monitoring of the Slave stations directly at the office of the Scientific Authority (if connected to the telecommunication network).

4) The Master station of the monitoring system is capable of handling up to 256 sensors. The Kaiser Mines may take advantage of this by connecting any other type of sensors to the system (in exchange for the power supply). The Consultants have the

abilities to help the Scientific Authority and/or Kaiser Mines in the design and adaptation of the monitoring system to other types of sensors.

5) It would be very desirable to increase the number of tiltmeters from five to ten, at an additional cost of $\approx$ $30,000.

Respectfully submitted,

W. Faig, P. Eng.

:lan

terra technology

June 29, 1979
Ref. No. COM/305/79

Dr. W. Faig
Department of Survey Engineering
University of New Brunswick
Fredericton, New Brunswick
Canada E3B 5A3

Subject: Biaxial Accelerometer Data
Reference: Telecon of June 28, same subject

Dear Dr. Faig:

Further to our conversation of yesterday, we have run a temperature test of the bias (null) stability of a typical tilt sensor unit over the temperature range of -40 °C to +50 °C. The data is tabulated below:

MODEL NO. SA-102 S/N: 642

Scale Factor: 2.50 volts/g

TEMPERATURE	BIAS (MV)	BIAS MG	EQUIVALENT ANGLE (Degrees)
50 °C	+8.5	+3.4	0.194
22 °C	+3.5	+1.4	0.08
-10 °C	0.5	-0.2	-0.011
-40 °C	-2.0	-0.8	-0.046

The overall temperature coefficient from +50 °C to -40 °C is 0.002667 degrees/°C.

I have also included some data from tilt sensors which we operate from 0 °C to 125 °C. While the temperature range limits are different than yours, it does demonstrate behavior over an even broader temperature range than the one you will be using.

TERRA TECHNOLOGY CORPORATION
3860 148th Avenue N.E. • REDMOND, WASHINGTON 98052 • (206) 883-7300 • Cable: TERRATECH • TELEX: 32-0357

Page 2
Ref. No. COM/305/79

The drawings and specification control documents enclosed show some of our typical biaxial inclinometer configurations. Some of these are used as surface tilt sensors and others are used inside of drill strings for directional drilling information. Regardless of the final application, all sensors and electronics are basically the same. The variations are the viscosity of the damping fluid used, scale factor, dynamic response, allowable stability error versus temperature and the operating temperature range. In all units, the operational parts of the two axes are independent so that, if a problem should develop in one axis, it will cause no degradation in the other axis. Even if one axis fails, a simple rotation of the unit will still provide tilt information in the other axis. As you will no doubt conclude from the drawings, our biaxial inclinometers tend to be somewhat custom in the final form factors. The sensors/electronics are all identical, but the outside dimensions of the packages are all somewhat different. The basic package is 1.0 inch in diameter by about 7 inches long. Some units are up to 11-12 inches long, but the O.D. stays the same. Most users find this basic packaging arrangement very convenient to use due to its small size and cylindrical shape.

If, after reviewing the enclosed information, you have any questions, please feel free to contact me. We look forward to the opportunity to serve your instrumentation needs.

Very truly yours,

TERRA TECHNOLOGY CORP

Charles O. Meyer
Vice President

COM:cs

P.S. Your letter just arrived. We are most anxious to receive your unit and make a final determination as to the cause of the low temperature malfunction. As further information I have also enclosed a copy of our paper, "Theory of Operation of Servo Accelerometers."

PPS: Just discovered another unit that we have available like the one you tested. We have shipped it to you hoping you can test it next week. Its angular temperature coefficient is 0.00032 degrees/°C.

APPENDIX II

Details regarding direct labour charges:

EVENT	Faig	Chrzanowski	Kurz	Makosinski	Hale
Project conference	2	2	2	2	2
Final electr. design	2	2	60	6	-
Parts procurement	15	5	5	15	-
Package and anchor design	5	5	5	20	-
Calibration of sensors	10	10	-	10	-
Construction of Master	2	2	5	20	-
Construction of Slaves	5	5	5	90	-
Laboratory testing	7.5	7.5	45	45	-
Field Testing	22.5	-	22.5	22.5	5
Software programming	22.5	7.5	60	7.5	-
Travel & site selection	30	30	15	15	-
Installation	40	40	40	40	-
In-site test	7.5	7.5	15	15	-
System evaluation (after 2 months)	5	10	5	5	5
Seminar in Calgary	-	22.5	22.5	-	-
Monthly reports	24	12	12	12	5
Final report	37.5	15	5	5	5
Total:	237.5	183	324	330	22

APPENDIX III

Preliminary List of Components - Electronic

1. Slave All IC's Ceramic Packages, extended temperature range

	1	Microprocessor	CDP 1802D	RCA	$ 29.94
	2	I/O-part	CDP 1854	" $9.74 ea.	19.48
	1	UART	CDP 1854	"	15.64
	1	RAM	CDP 1823	"	17.52
	2	EPROM	MM4203Q	National $94.57 ea.	189.14
	1	Latch	CDP 4042	RCA	1.27
	1	Decoder	CDP 1853	"	6.66
	1	Bit Rate generator	MC 14411P	Motorola	13.80
	1	NAND gate (CMOS)	4011	RCA	.56
	1	Modem	MC 14412 VP	Motorola	16.83
	3	Active Filter	AF 100 1CY	National $8.77 ea.	26.37
	3	Crystals 1MHz, 1MHz, 1.843M Hz		$7.00 ea.	21.00
	1	Multiplexer	CDP 4051B	RCA	2.08
	1	Sample/Hold	LH0043	National	35.26
	1	A/D - Converter	MM 4357	National	35.52
	1	Nand gate (CMOS)	CD 4011	RCA	.56
	3	Trim potentiometer		$1.25 ea.	3.75
	6	1% resistors, ¼ W		$0.20 ea.	1.20
	1	-5V regulator (30m A max.)		$2.62 ea.	2.62
Approx.	20	resistors, 10%, ¼ W		$0.10 ea.	2.00
	1	Thermistor, $-40^{o}C$. . $+70^{o}C$			7.50
	1	Schmitt-Trigger gate (CMOS)	CD40106-Hex	CA	1.41
	1	Tranceiver HT-210		Motorola	970.00
Glove	(2	Batteries 12V/6AH - GC1260-1B (10 Qty)		$40.90 ea.	81.80
gel-cells	(2	Batteries 12V/ 30 AH Globe U-1223 (10 Qty)		$65.91 ea.	131.82
	5	circuit boards			25.00
Approx.	35	capacitors		$0.35 ea.	12.25
	2	+5V regulators (30 m A max)		$1.56 ea.	3.12
	2	power switches			5.00
	1	RCV/XMIT-switch			5.00
	2	Waterproof-cases & hardware			200.00
	2	connectors		$20.00 ea.	40.00
					$ 1,924.04
				+ 9% FST	173.16
					$ 2,097.20

APPENDIX III (continued)

2. Master

				Duty Incl.
	1	Calculator HP9815A	HP	$4,416 + 7% FST
	3	Active Filter AF100 1CJ	National	26.31
	1	Modem MC14412	Motorola	16.83
	2	UART CDP1854	RCA	31.28
	2	Baud Rate Gen. MC14411	Motorola	27.60
	2	Crystals 1.843 MHz		14.00
	1	Base Station	Motorola	1,140.00
	2	GP-I/O interfaces	HP 280	650.56
		Power supplies	± 12V @ 100 mA	48.00
Approx.	10	resistors, 10%, ¼ W		1.00
Approx.	20	capacitors		7.00
	2	Circuitboards		10.00
	1	Antenna		132.00
	1	Cable to antenna		25.00
	1	Cabinet with hardware		175.00
				$ 6,720.58
			+ 9% F.S.T.	604.85
			Total	$ 7,325.43

3. Relais-Station All IC's Ceramic Packages, extended temperature range.

	1	Microprocessor CDP1802	RCA	$ 29.94
	2	I/O - part CDP1852	"	19.48
	1	RAM CDP1823	"	17.52
	2	EPROM MM4203	National	189.14
	1	Latch CDP4042	RCA	1.27
	1	Decoder CDP1853	"	6.66
	1	Nand gate (CMOS) 4011	"	.56
	1	Crystal 1MHz		7.00
	2	Active Filters AF100	National	17.54
	2	Transceivers HT-210	Motorola	1,940.00
Approx.	10	resistors 10%, ¼ W		1.00
Approx.	20	capacitors		7.00
	1	Schmitt-Trigger gate (CMOS) 0106 RCA		1.41
	2	circuit boards		10.00
	1	power switch		5.00
	2	RCV/XMIT-switches		5.00
	1	Battery 12V/ 40 Ah		94.00
	2	Batteries 12V/ 10 Ah		81.80
	2	+5V regulators (30 mA max)		3.12
	1	Waterproof steel container and hardware		200.00
				$ 2,631.54
			+ 9T F.S.T.	236.84
				$ 2,868.38
			+ $1700 labour	1,700.00
				$ 4,568.38

REQ. NO. 8-9016

ECOLOGICAL AND RESOURCES CONSULTANTS LIMITED
508 CHARLOTTE STREET, FREDERICTON, NEW BRUNSWICK, CANADA E3B 1M1 TEL. (506) 455-5278

CONTRACT REPORT NO. OSQ78-00238

MONTHLY REPORT, PHASE II

OCTOBER 1979

DEVELOPMENT, INSTALLATION AND OPERATION OF A SUBSIDENCE MONITORING AND TELEMETRY SYSTEM

DSS FILE:
18SQ.23440-8-9016

RN: 23440-8-9016
FC: 359-132-000000-334100-0433
CONTRACT SERIAL # OSQ78-00238

SUBMITTED BY:

Ecological and Resources Consultants Limited
508 Charlotte Street
Fredericton, N. B. E3B 1M2

19 pp

MICROMEDIA
MAY 13 1983

PROGRESS REPORT COVERING THE PERIOD OCTOBER 1-31, 1979

While waiting for delivery of the electronic components ordered in September, the design of the Slave Unit was finalized. This permits commencement of the construction of the proto type immediately upon arrival of the necessary parts.

A small debug-monitor program has been written which provides insight into the memory of the microprocessor unit.

A utility program, which permits the cross assembly on the IBM 370 system for RCA 1802 assembler programs has been written, installed and tested.

Furthermore, arrangements have been made for utilizing the thermostat controlled cooling chamber when calibrating the tiltmeters.

Focussing on the major accomplishment for October, 1979, the final design of the Slave Unit's electric circuitry is presented. Circuit diagrams are given along with the descriptive sections outlining the functional operation of the electronic modules.

The final design is based on the preliminary work carried out in Phase I of the project. Investigations performed previously (see May, June, 1979 Reports) led to recommendations for the final electronic design. These recommendations are adhered to strictly, except for slight changes necessitated by particular hardware. Any of these modifications are indicated in this report.

The final electronic design was carried out in stages, addressing individually the following modules (see Figure 2.5, June '79 report):

(i) Microprocessor Control Unit, MPCU,
(ii) Miniterminal (not contained in Phase I report),
(iii) Data Acquisition Module, DAQM,

(iv) Telemetry Module, TLM,
(v) Power Distribution Unit, PDU,
(vi) Interconnection Scheme between modules in (i) through (v).

The following chapters deal with the above modules in detail and particularly address technically minded persons wishing to familiarize themselves with the Slave's electronic circuitry, and for reference purposes in future maintenance and repair work.

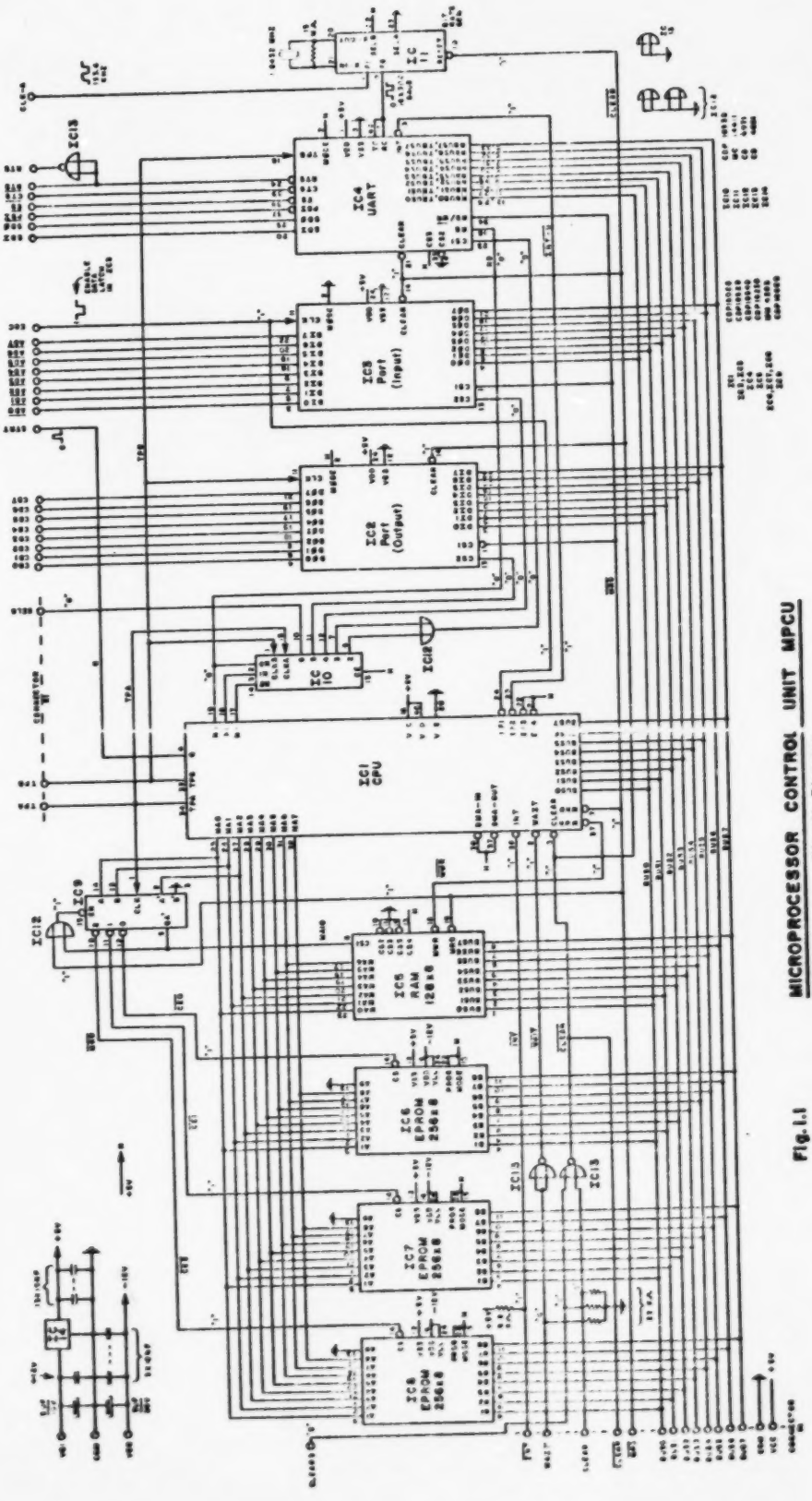
1. Microprocessor Control Unit, MPCU

The Microprocessor Control Unit, MPCU, utilizes the RCA1802D microprocessor for its low power and wide temperature range application, along with associated memory and peripherals.

The circuit diagram in Figure 1.1 shows the detailed interconnection scheme between processor modules, as well as data and control bus structure, and external bus access for input/output operation.

Integrated Circuit IC1 represents the central processor unit (microprocessor) CDP1802D. A total of 128 bytes of Random Access Read/Write memory (RAM) is provided by IC2, CDP1823D, which is used by the control software as buffer, status flags and as a scratch pad. The control program resides in a maximum of three Erasable Programmable Read-Only memories (EPROM), IC6 through IC8, MM4203, providing a total of 768 bytes. The third memory, IC8, is reserved for the Debug Monitor program.

The memory address space, defined by 16 memory address lines MA0 through MA15 is configured such as to achieve a simple decoding procedure for the chip select inputs (CSi) of the individual memories. One address



MICROPROCESSOR CONTROL UNIT MPCU

Circuit Diagram

Fig. 1.1

line (MA10) selects between RAM or EPROM memory with two lines (MA9, MA8) selecting one out of three EPROM devices. The lower order address line (MA0-MA6 and MA0-MA7, respectively) serve for on-chip address purposes. As the RCA 1802 microprocessor operates a multiplexed memory address bus (16 address bits on 8 address lines), the higher order address byte is held in IC9 and also decoded there. The two control signals MWR and MRD gate appropriate data from/to the common bidirectional data bus, BUS0 through BUS7, as required during memory write/read instruction cycles. The Read-Only memories, IC6-IC8, can only be addressed during a read cycle. The resultant memory address space is illustrated in Figure 1.2(a) with the bit assignment of the memory address bus appearing in Figure 1.2(b).

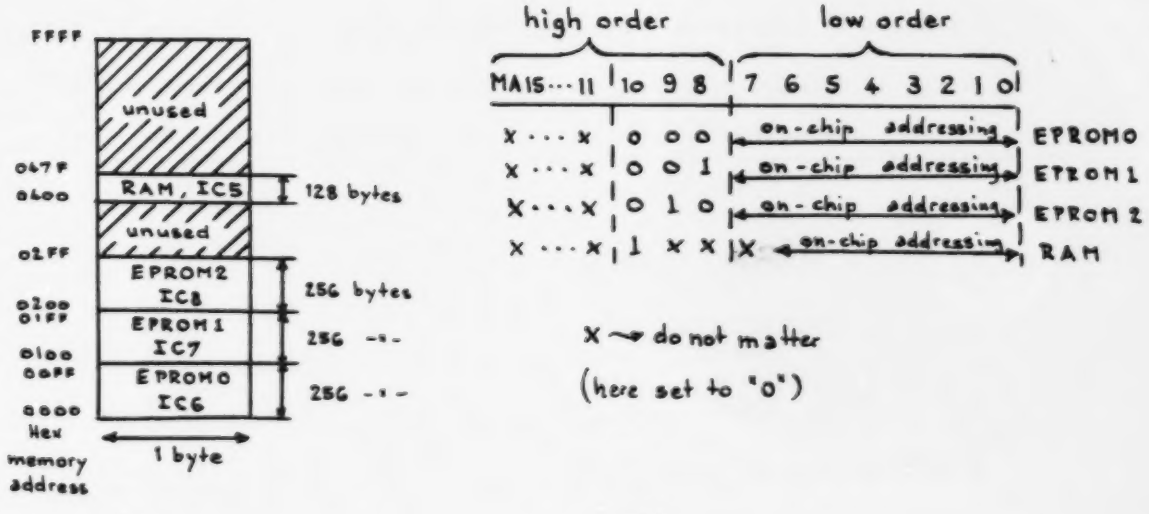


Fig. 1.2 Configuration of Processor Memory
(a) memory address space and
(b) memory address bus utilization.

The devices IC2 through IC4 serve as input/output peripherals to the RCA1802 processor. They permit communication with external logic modules. The addressing of the peripherals is accomplished in the non-memory mapped mode. Therefore, special address lines, NO-N2, are used to select individual peripherals via the decoder IC10, CDP1853D. The applicable addressing scheme is illustrated in Fig. 1.3 which specifies the 'N' code of the processor's input/output instructions. The read/write mode of the peripherals is established by the control signals MRD and MWR, and data is passed between the latter and the processor over the bidirectional data bus, BUSO-BUS7.

The port IC2, CDP1852D, serves as parallel 8-bit output port holding the signals CDO-CD7 (for control of external logic modules) after execution of an appropriate output instruction by the processor with a single address code of N=5, see Figure 1.3. This port can only be written to from the processor and generates no interrupt. The assignment of the function associated with the output byte CDO-CD7 is given in

	peripheral	N-code	Function	Instruction
IC3	input port	4	read	INPUT 4
IC2	output port	5	write	OUTPUT 4
UART IC4	transmit data	2	write	OUTPUT 2
	receive data	2	read	INPUT 2
	control	3	write	OUTPUT 3
	status	3	read	INPUT 3
Keypad IC104	input port	6	read (upon interrupt)	INPUT 6
Display IC105	output port	6	write	OUTPUT 6

Fig. 1.3 - Addressing Scheme of Peripheral Interfaces Using N Code Selection.

Figure 1.4.

The port represented by IC3, CDP1852D, serves as input port accepting 8 bits of data from the analog-to-digital converter of the DAQM. The bit assignment is shown in Figure 1.5. This data is latched into IC3 when conversion is completed, that is when EOC is high. The signal EOC can also be sensed by the microprocessor at its input EF1 to detect whether or not data conversion is in progress. Peripheral IC3 can only be read from by a single address code of N=4, (see Figure 1.3), and no interrupt is associated with it.

The peripheral interface IC4 represents a Universal Asynchronous Receiver/Transmitter (UART), CDP1854D, and establishes bidirectional communication with the Telemetry Module, TLM, through serial asynchronous data flow. In Figure 1.3 the multi-address N code to be used with the UART is shown. For N=3, the status and control register can be read from or written to, respectively. Coding N=2 selects the data register

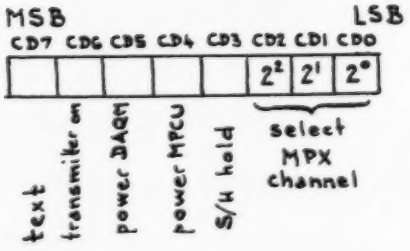


Fig. 1.4 - Logic Module Functions associated with the Output Word CDO-CD7. A logical "1" enables The Function(s) indicated.

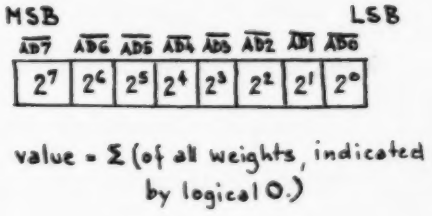

MSB
LSB
$\overline{AD7}$ $\overline{AD6}$ $\overline{AD5}$ $\overline{AD4}$ $\overline{AD3}$ $\overline{AD2}$ $\overline{AD1}$ $\overline{AD0}$
2^7 2^6 2^5 2^4 2^3 2^2 2^1 2^0
value = Σ (of all weights, indicated by logical 0.)

Fig. 1.5 - Bit Assignment for the Input Word AD0 - AD7. Note the inverted Logic.

for input or output. Serialized data appear at terminals SDI (input) and SDO (output) along with the appropriate control signals, RTS, CTS. External flags can be passed to the UART via ES and PSI (here not used) terminals. The interrupt signal INT of the UART is sensed by EF2; it is, however, not used directly as processor interrupt. The receive and transmit bit rate are set to be 300 baud and are selected by the Bit Rate Generator IC11, MC14411 at output F9 (16 x 300 Hz=4800 Hz). A CLK-A signal of 150.6 KHz rate is available at output F1 of IC11 which is used as clock for the DAQM.

The data bus BUS0-BUS7, as well as several control signals, MRD, CLEAR1, WAIT, INT, TPA and TPB are externally accessible at connector R1 for use with the Miniterminal. With the Miniterminal removed, the control signals CLEAR1 and WAIT assume a state which causes the microprocessor to enter the run mode. The input labeled CLEAR0 is used to initiate the restart sequence of the processor after the completion of the power up period. It is generated by the PDU after receiption of an ALERT call from the Master Station.

The microprocessor IC1 is operated at a clock frequency of 1MHz. This rate is a compromise between low power consumption and fast program execution. At this rate instruction times amount to between 16 μsec and 24 μsec. Detailed program execution timing will be available with the software description.

2. Miniterminal

The Miniterminal has not been mentioned during the Phase I reports. It has been designed with ease and speed of microprocessor maintenance and debugging in mind. The Miniterminal is not part of the MPCU of an individual Slave, but can be connected to any MPCU during field tests. After the testing session, the Miniterminal is removed for use with other Slaves.

The Miniterminal permits the input of hexadecimal data into the processor and the display of memory data. As well, it provides run control (single step, continuous, pause) of the processor to achieve static operation, particularly useful with the RCA1802's static operation. Its operation is supported by the interrupt driven Debug Monitor. (see Figure 3.5, June '79 report).

Figure 1.6 shows the circuit diagram of the Miniterminal. The data input facility consists of the hexadecimal keypad ($0-F_{16}$) with associated encoder devices, IC106 through IC108. The encoders pass a 4-bit binary key identification to the input port IC104. Upon depressing a key, the dual one-shot IC109 (CD4528) latches the encoded data into IC104 when LD is high and generates an audible buzz as positive feedback to the User. The input port IC104 is addressed by the single-address code N=6 during a read instruction as shown in Figure 1.3. The bit assignment of the data word read is shown in Figure 1.7(a). When LD goes low, an interrupt is generated which signals the processor that a key has been pressed by the user. This is the only interrupt driven function implemented in the MPCU.

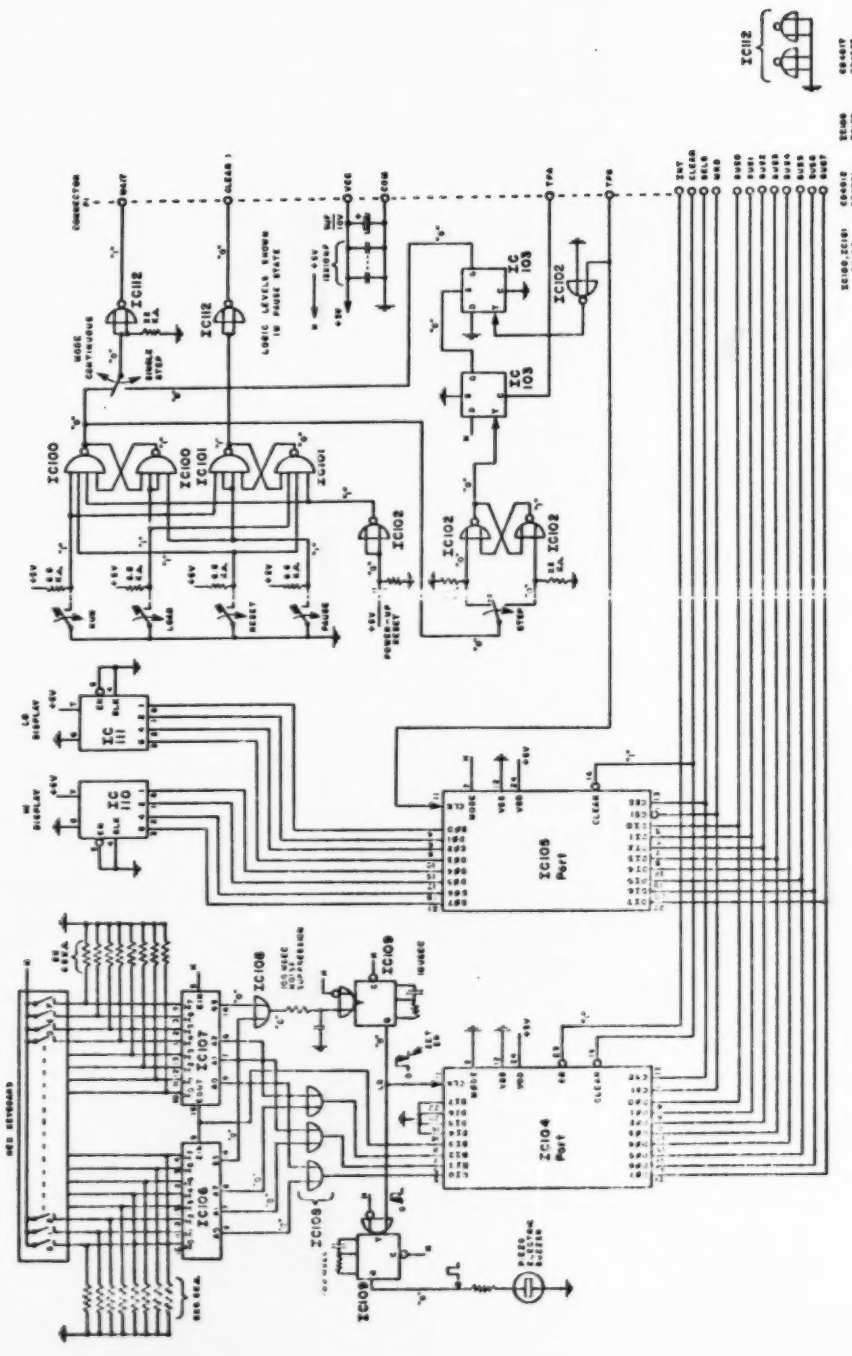
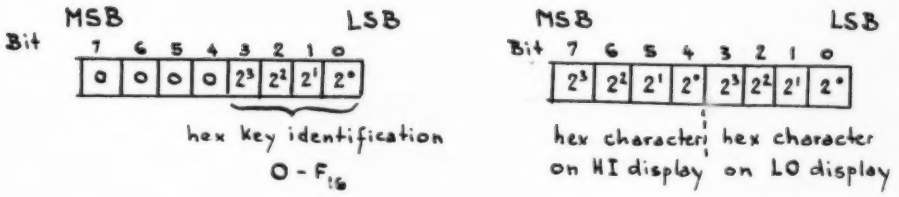


Fig. 1.6 MINITERMINAL FOR MPCU (RCA 1802)
Circuit Diagram



(a) (b)

Fig. 1.7 - Bit Assignment for Miniterminal,
(a) read from hexadecimal key pad,
(b) write memory data (byte) to display .

An 8-bit memory word can be written to the display via the output port IC105, CDP1852D. The output port is written to by a single-address code N=6 as shown in Figure 1.3. The data is held in IC105 and the corresponding hexadecimal character representation appears immediately on the two-character display as illustrated in Figure 1.7(b). This port can only be written to, and no interrupt is associated with it.

Data is transferred from/to the microprocessor via the bidirectional data bus BUS0-BUS7. Peripheral addressing is accomplished through the SEL6 line (N=6) and the MWR, MRD direction signals.

Run control of the microprocessor RCA1802 is exercised via four push-button switches labeled RUN, LOAD, RESET and WAIT. The appropriate signals CLEAR1 and WAIT are generated by the logic consisting of IC100 through IC103 and IC112 and are passed on to the MPCU via the connector P1 (mating with R1). The correct timing of these signals is ensured by triggering the logic with the processor timing pulses TPA and TPB.

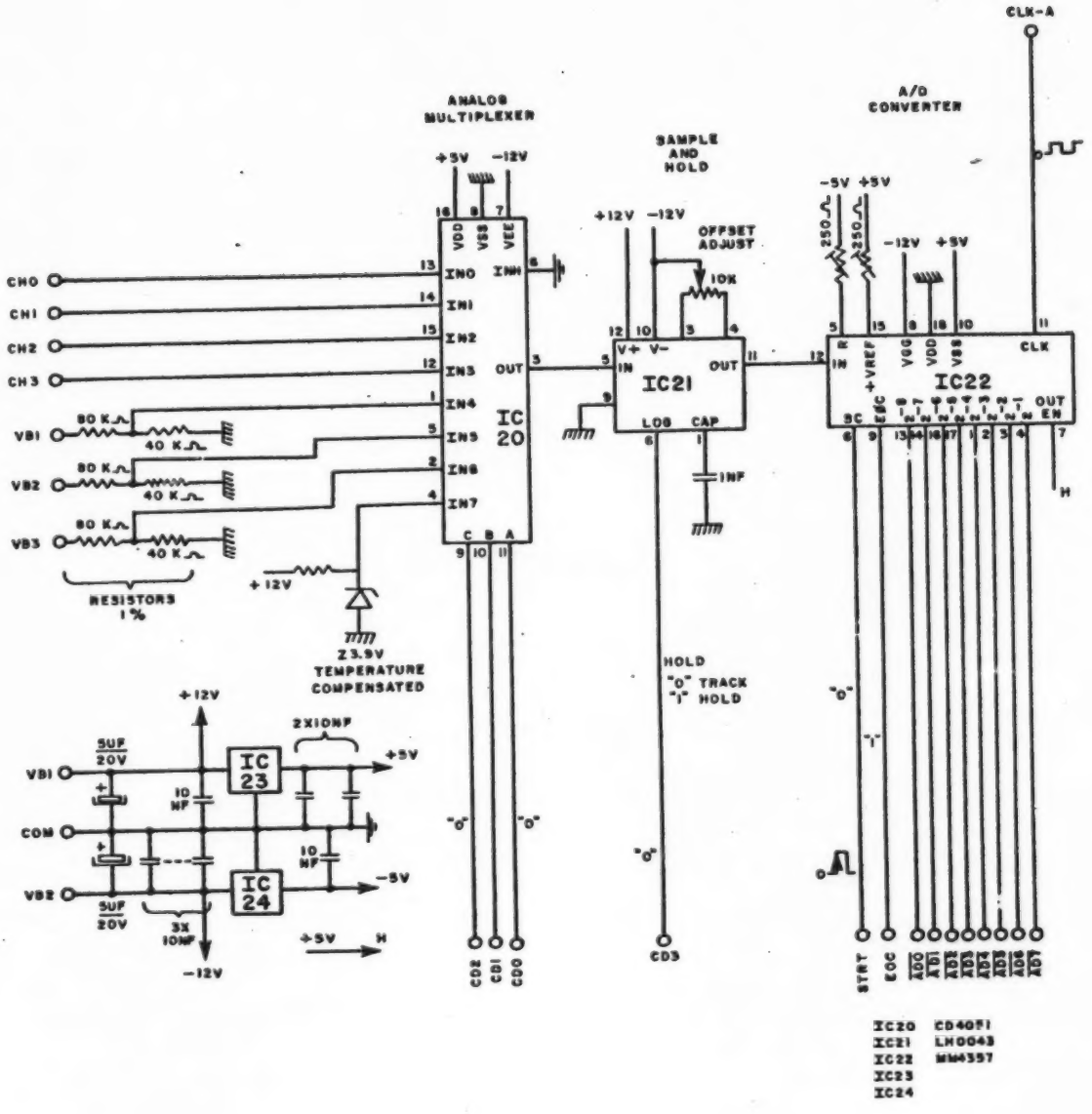


FIG. 1.8 DATA ACQUISITION MODULE DAQM

Circuit Diagram

Apart from the above state control, the processor can be single stepped (single machine cycle, not single instruction cycle) or run continuously. The MODE control switch must not be operated when the RUN mode is selected to avoid unpredictable results.

3. Data Acquisition Module, DAQM

The Data Acquisition Module, DAQM, serves the purpose of selecting and digitizing analog signals and passing the representative digital word to the MPCU via the input port IC3 (see Figure 1.1). The MPCU's output port IC2 is used to select the desired analog signal.

Figure 1.8 shows the circuit diagram of the DAQM. A total of 8 analog input channels are selected by the analog multiplexer IC20, CD4051 in accordance with the binary values of the control lines CD0-CD2, see Figure 1.4. The utilization of the channels is listed in the table in Figure 1.9. Four inputs are available for external use with sensors and four inputs are reserved for internal test use. The bipolar input voltage range at either channel is -5.0 through +4.961V.

Channel	Selected by CD2	CD1	CD0		Use
In0	0	0	0	CH0	External use for sensors, -5 to +5V input range
In1	0	0	1	CH1	
In2	0	1	0	CH2	
In3	0	1	1	CH3	
In4	1	0	0	test	VB1 battery voltage, +12V
In5	1	0	1	test	VB2 battery voltage, -12V
In6	1	1	0	test	VB3 battery voltage, +12V
In7	1	1	1	test	DAQM operation (apply +4V)

Fig. 1.9 - Table of Analog Channel Utilization

The Sample-and-Hold Unit IC21, LH0043 tracks the output signal of the multiplexer as long as CD3 is low, and holds it otherwise. The permissible output voltage drop-off is $< 150 \frac{mV}{sec}$ $(= \frac{39 \text{ mV resolution}}{260 \mu\text{sec conversion time}})$ as prescribed by the performance of the Analog-to-Digital Converter (ADC) represented by IC22, MM4357. The ADC digitizes the input data into a representative 8-bit data word, AD0-AD7, using offset binary representation. The pertinent bit assignment is shown in Figure 1.7(b) where the weighted data word and the actual digitized voltages are related by V =[0.03906 x $\sum$ (all weights indicated by locigal zero)] -5.000 Volts. The conversion scheme is outlined in more detail by the table in Figure 1.10. The indicated range is accomplished by properly adjusting the two range control potentimeters connected to the ACD, IC22, see Figure 1.8. Data conversion is started after settling of the input voltage of the ADC by a STRT pulse derived from the Q output of the microprocessor IC1, Figure 1.1. During conversion EOC goes low, and it returns to high upon completion of conversion. The signal EOC is used for data latching and as sense input to the processor as described in Section 1. The clock CLK-A is of frequency 153.6 KHz determining the conversion period as 260 μsec.

The DAQM is designed to satisfy the overall performance criteria as shown below for the worst case situation. Offset and range adjustments are to be made at IC21 and IC22 accordingly.

analog voltage Volt	binary representation AD7	6	5	4	3	2	1	0
+4.961	1	1	1	1	1	1	1	1
+4.922	1	1	1	1	1	1	1	0
⋮				⋮				
+0.039	1	0	0	0	0	0	0	1
0	1	0	0	0	0	0	0	0
-0.039	0	1	1	1	1	1	1	1
⋮				⋮				
-4.961	0	0	0	0	0	0	0	1
-5.000	0	0	0	0	0	0	0	0

Fig. 1.10 - Analog-to-Digital Conversion Scheme.

Note that AD0-AD7 are inverted in Figs. 1.5 and 1.8.

Input Voltage range :-5.000V to +4.961V

Input resistance at multiplexer terminals : $> 10^{10}\ \Omega$

Analog signal acquisition time : typ 4 μsec for 5V step

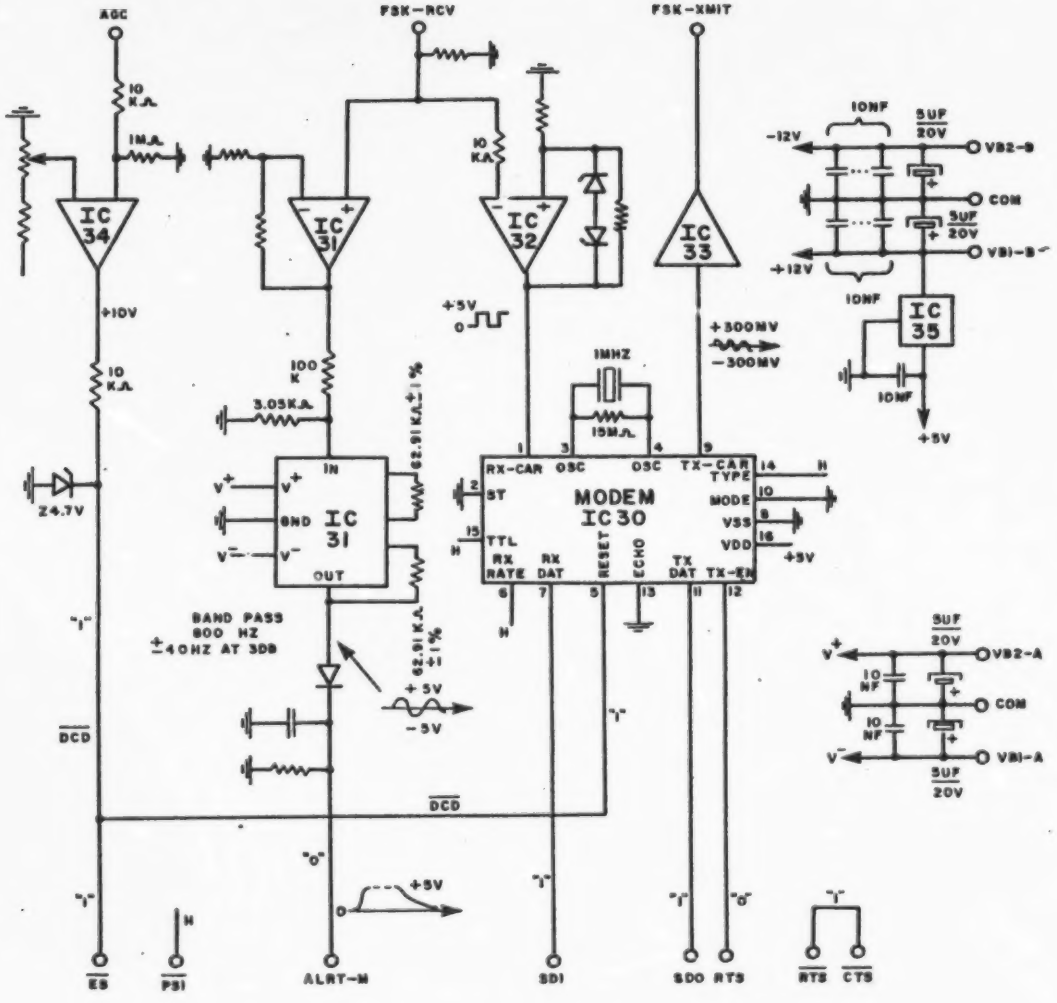
Data conversion time : 260 μsec

Resolution : 39 mV (1 LSB)

Accuracy : $\leq \pm$ 1LSB ($\pm$ 39 mV) over full range

Linearity : $\leq \pm$ 1LSB ($\pm$ 39 mV) over full range

Operating ambient temperature range : $-40^{\circ}C$ to $+40^{\circ}C$



IC30 MC14412
IC31 AF100
IC32, IC33, IC34
IC35

FIG. 1.11 TELEMETRY MODULE TLM

Circuit Diagram

4. Telemetry Module, TLM

The Telemetry Module, TLM, provides the modulation and demodulation of the serial asynchronous data stream between the MPCU and the VHF-Radio Tranceiver. It also serves the detection of the Alert call issued by the Master Station.

The circuit diagram is illustrated in Figure 1.11. The low speed modem is represented by IC30, MC14412. The modem employs frequency-shift keying (FSK) for modulation purposes. The US standard frequencies in the answer mode are selected and are tabulated in Figure 1.12. Seralized data SDO is modulated and applied to the VHF transmitter as FSK-XMIT via the buffer IC33. The VHF receiver signal FSK-RCV is limited by the amplifier IC32 to obtain the required square wave signal with (50±4)% duty cycle which is demodulated and sent as serial data SDI to the MPCU. Demodulation is inhibited when DCD is low and modulation is enabled by RTS being high. The modem's operation is optimized for the data rate of 300 baud.

The Alert signal issued by the Master Station is indicated by an 800Hz tone which is detected by the active filter IC31, AF100, tuned to 800Hz with 80Hz bandwidth (-3dB). The filtered Alert tone is rectified and passed to the Power Distribution Unit as ALRT-M signal. The rise time of ALRT-M is determined by the 80Hz bandwidth of IC31 to be approximately 1/Bandwidth=12.5 msec. The RC combination at the output of IC31 (including the load represented by the PDU) is selected such that, after removal of the Alert tone, ALRT-M stays in logical "1" range for approximately 1 sec. This operation is part of the fail-safe procedure described in detail in Section 4 of the May, 1979, report and gives the MPCU time to

bootstrap its own power.

The AGC (automatic gain control) signal of the VHF transceiver is utilized as data carrier detect, DCD, control signal and can be sensed by the MPCU via ES. The comparator IC34 is set to the threshold above which reliable radio reception is ensured.

Function	Mark ("1")	Space ("0")	Alert -M tone
Transmit	2225 Hz	2025Hz	=800 Hz
Receive	1270Hz	1070Hz	

Fig. 1.12 - FSK Carrier Frequencies for US Standard, Answer Mode, as used by Slave.

5. Power Distribution Unit, PDU

This module is presently under design and will be described in the next report.

6. Module Interconnections

The interconnection scheme of the electronic modules of the Slave is shown in Figure 1.13. The denotation of the signals is identical to that used in the circuit diagrams of individual modules.

Respectfully submitted,

lan

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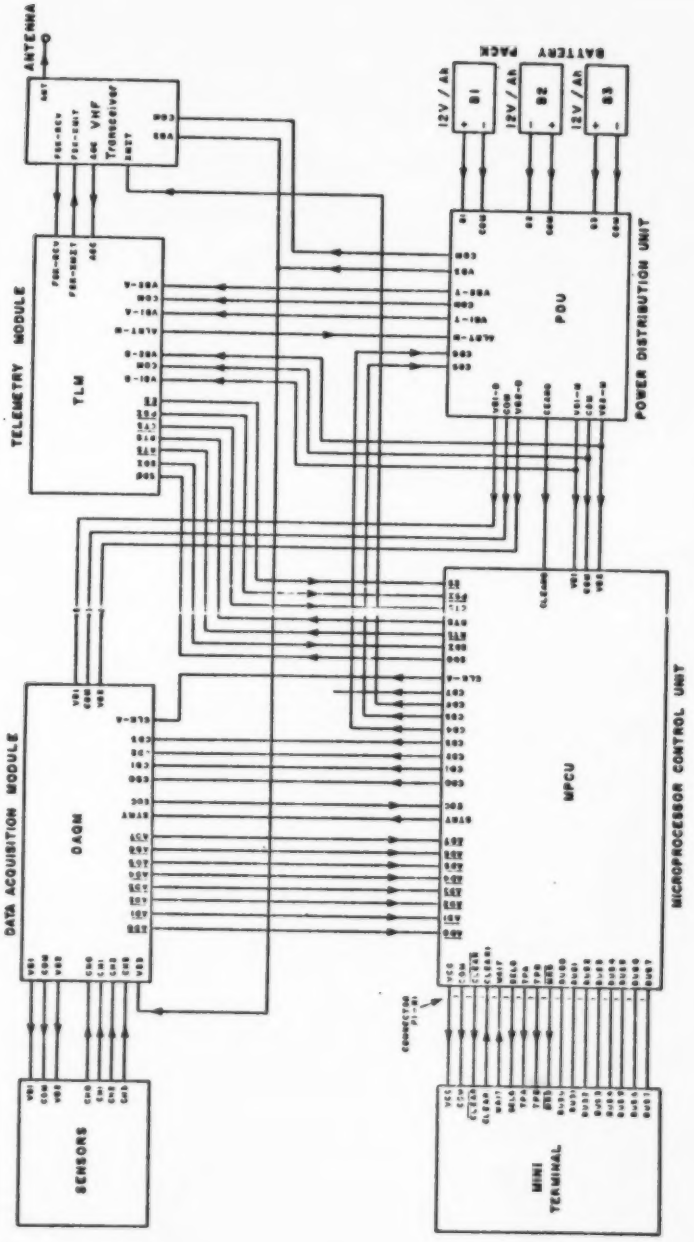

FIG. 1.13 SLAVE ELECTRONICS - INTERCONNECTION SCHEME